NASA-ASEE

2002 NASA FACULTY FELLOWSHIP PROGRAM AT GLENN RESEARCH CENTER

FINAL REPORT

OAI
Leveraging Resources Through Collaboration

CASE WESTERN RESERVE UNIVERSITY

NASA FACULTY FELLOWSHIP PROGRAM AT NASA GLENN RESEARCH CENTER AT LEWIS FIELD CLEVELAND, OHIO

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In Memoriam

This report is dedicated to the memory of Professor Patrick M. Flanagan of Cleveland State University who was actively involved with the Glenn research community over the years. His untimely passing while a participant in the 2002 NASA Faculty Fellowship Program was deeply felt by all who knew him.

CONTENTS

INTRODUCTION

The NASA Faculty Fellowship Program (NFFP) is conducted at each of the NASA field centers. Administered jointly by the American Society of Engineering Education (ASEE) and the Universities Space Research Association (USRA), NFFP incorporates characteristics of NASA/ASEE Summer Faculty Fellowship Program and the NASA/USRA Joint Venture (JOVE) program, two long running, successful NASA programs. This report summarizes the 2002 session conducted at the Glenn Research Center (GRC). Including all prior years of the ASEE Summer Faculty Fellowship Program this was the 39th consecutive session of the program a GRC. GRC has conducted the program since 1964, the year the program was instituted a NASA, originally involving only a few centers.

At each center, management of the program is shared between one or more educational institutions. At GRC, two institutions, the Ohio Aerospace Institute (OAI) and Case Western Reserve University (CWRU), a member of OAI, serve as concurrent partners – thereby involving the NASA co-director and two university co-directors each year.

The expressed primary objectives of the program are:

(1) To increase the quality and quantity of research collaborations between NASA and the academic community that contribute to NASA's research objectives;
(2) Tp provide research opportunities for college and university faculty that serve to enrich their knowledge base;
(3) To involve students in cutting-edge science and engineering challenges related to NASA's strategic enterprises, while providing exposure to the methods and practices of real-world research;
(4) To enhance faculty pedagogy and facilitate interdisciplinary networking;
(5) To encourage collaborative research and technology transfer with other government agencies and the private sector; and
(6) To establish an effective education and outreach activity to foster greater awareness of this program.

The last objective is of critical interest to NASA and deserves further elaboration. From a broader perspective NASA sees the NASA Faculty Fellowship Program as a vehicle for initiating lasting partnerships in the academic community. While research assignments result in immediate contributions to host organizations, the development of longer-term collaborations has far greater potential for NASA programs. Such developments are welcome. Opportunities to move from fellowships to funded grants, which fuel lasting collaborations, are always a matter of interest to fellows and NASA colleagues alike though they never can be assured. At all centers, fellows spend 10 weeks in residence working on research assignments in collaboration with designated NASA colleagues and generally participating in other organized professional activities. Appropriate social activities are also arranged for the fellows, and their families. All fellows receive a stipend, which was $1200 per week in 2002. The program is open only to U.S. citizens, and participation is limited to two consecutive residencies. Implementation of the program varies at each center within broad guidelines established by the NASA Headquarters Education Division in partnership with ASEE.

THE GLENN RESEARCH CENTER PROGRAM

At GRC, the program focus is primarily on the intensity and quality of the individual participant's research experience in collaboration with the NASA colleague and less on structured group activities. The latter are considered ancillary activities. The focus has been determined by the co-directors from many years of experience to produce the greatest benefits and satisfaction, programmatically and educationally, to NASA and the program participants.

After initial administrative screening, applications are reviewed by the NASA co-director for its technical interests and qualifications. The applications are then circulated to appropriate research organizations for review in consideration of the organizations' immediate technical needs. Selection of the applicants is made by the research organizations. If an organization desires to host a fellow, it prepares a written statement of the proposed assignment that is sent to the applicant along with an offer of award. The assignment is designed to match the interests and qualifications of the applicant, to be professionally challenging, and to enable meaningful results to be accomplished in 10 weeks. This process assures good matches between the interests of the faculty and the programmatic needs of NASA.

GRC also offers an Accompanying Student Option whereby faculty may be accompanied by one of their students for the full duration of their fellowship. In this arrangement, the student is not formally given a NASA mentor. Instead, the on-campus professor/student relationship is intended to be sustained in the center research setting. Nomination and selection of the students is accomplished on an *ad hoc* basis in consultation with the NASA co-director.

In response to 117 applications received, offer letters were sent to 33 faculty, and 30 accepted. The 30 acceptances represented 22 faculty who were new to the program and 8 who were returning.. In addition, 1 student was admitted to the program to accompany her professor, for a total of 31 participants in the program.

Participants are encouraged to devote their best efforts to their research. Attendance at ancillary activities offered by the program to promote a group identity and facilitate professional interaction is always optional. While less emphasis is placed on this activity, considerable care is taken to insure that the quality of the activity is a strong motivator for attendance. This approach has proven successful over many years.
The primary ancillary activity offered at GRC is a weekly lecture series organized by the university co-directors. The lecture series features invited speakers, usually from outside organizations, on a variety of carefully selected subjects. All students who are at GRC concurrently in a variety of programs are also invited to the lecture series, and an opportunity is provided before each lecture for the faculty and students to interact informally and to socialize. The lectures offered in 2002 are listed in Appendix A.

In addition to the lecture series, the participants and their families were invited to a reception at the GRC Conference Center in the second week of the program to meet with other program participants and with the center officials, a mid-program picnic at the GRC recreation area, and a closing banquet. On the first day of the program, participants attended a kickoff orientation at which they were provided with a variety of printed material describing amenities of the Cleveland metropolitan area for their private pursuits. The program began officially with the orientation meeting on June 3, 2002 and concluded on August 9, 2002. However, the actual dates of participation of some faculty deviated from these.

PROGRAM EVALUATION

Near the end of the program, the fellows completed a program evaluation questionnaire. A copy of the questionnaire is provided in Appendix B. All the data submitted were summarized in a single, comprehensive report for the co-directors and cognizant GRC supervisors. Analysis of the results was overwhelmingly positive and revealed that the purposes of the program are being successfully met.

RESEARCH SUMMARIES

While several objectives are served with this program, the central mechanism involved is the conduct of research assignments by faculty in direct support of NASA programs. In general, the results of the research will be assimilated by NASA program managers into an overall effort and will ultimately find their way into the literature. Occasionally, specific assignments result directly in reports for publication or conference presentation. Taken as a body, the assignments represent a large intellectual contribution by the academic community to NASA programs. It is appropriate therefore to summarize the research that was accomplished.

The remainder of this report consists of research summaries arranged alphabetically by participant name. For each summary, the faculty fellow is briefly identified and the assignment prepared by the GRC host organization is given. This is followed by a brief narrative, prepared by the fellow, of the research performed. Narratives provided by the accompanying students immediately follow the narratives of their professors.

Name: **Narahari B-N. Achar**
Education: Ph.D., Solid State Science
The Pennsylvania State University

Permanent Position: Professor, Physics
University of Memphis

Host Organization: Instrumentation and Controls Division
Colleague: 5530/Ten-Huei Guo

Assignment:

Application of the Fractional Calculus to Physics

This research will study the application of the Fractional Calculus to diffusion (and possibly wave) processes in gases and liquids. Application to Chemical Vapor Deposition (CVD) and fractional oscillators will be explored.

Research Summary Submitted by Fellow:

My project this summer was in the area of application of Fractional Calculus to problems of Physics. Fractional Calculus is hardly a household word even among the elite mathematicians. Very few engineers and physicists know about this area of mathematics, even though Fractional Calculus is just as old as the regular Calculus and was invented by the very Leibnitz who is considered to be the co-inventor of Calculus. The specific project that I worked on dealt with the question of initialization in a certain type of fractional derivatives called Caputo derivatives. Fractional derivatives are non-local in nature in contrast to the regular derivatives, which are entirely local. As such fractional derivatives carry the past "history" and include "memory effects." It is because of this that Fractional calculus finds applications in fields such as visco-elasticity, polymer physics, etc. The project proved to be more challenging than initially thought. However, it has been brought to a successful completion and the results will be published as a NASA-TM and will also be submitted as an article to a professional journal. It is anticipated that the paper will have a major impact in the field. The Caputo derivatives have been very popular in the engineering applications to visco-elasticity. Our work has shown conclusively that there are serious questions of consistency in the initialization process in the use of Caputo derivatives. Thus it will have a major impact in how the problems in the various fields mentioned will be treated in the future.

I also had the opportunity to interact with a research group in MEMS (Micro Electronic Machinery) and have developed an interest in the theory of Piezoresistance of Silicon Carbide, one of the primary materials used in MEMS application. It is anticipated that this interaction will lead to a better understanding of the fundamental physics in this material leading to improved device applications.

I also had an opportunity to give a talk at NASA and present the results of my research in Ancient Indian Astronomy using Planetarium Software, which went very well.

Name: **Philip Chen**
Education: Ph.D., Electrical and Computer Engineering
Purdue University

Permanent Position: Professor, Computer Science and Engineering
Wright State University

Host Organization: Instrumentation and Controls Division
Colleague: 5530/Ten-Huei Guo

Assignment:

Life Extending Control with System Uncertainties

A class of the Life Extending Control algorithm has been reported in the NASA/SMI ILEC contract. Where an intelligent open-loop scheduled N2dot is used to achieve the required performance while drastically reducing the Thermal-Mechanical-Fatigue (TMF) during the take-off. This summer research task is to explore the effects of the system uncertainties (from engine operating conditions, environmental inputs, and thermal and stress models) on TMF, and to design a controller that is suitable for the conditions while meeting the performance requirements.

Research Summary Submitted by Fellow:

This research project investigates the potential benefit of an intelligent life extending control logic (ILEC) applying to commercial gas turbine engines. The goal of this research is to study the stochastic nature of the Thermal Mechanical Fatigue (TMF) damage life due to sensor noises and parameter uncertainties. With proper modeling of uncertainty effects, better life usage models and better prediction of the probability of failure of engine operation can be established.

A methodology has been developed to reduce the life usages of gas turbine engines. The methodology was to modify the acceleration schedule of the engine operation in a typical flight mission and thus to reduce the TMF damage of cooled stators during the take-offs. A damage calculation model is included to the simulation and the acceleration schedule does slightly degrade the engine performance yet still meet the FAA requirements.

The statistical analysis of TMF damage life due to the noises of flight conditions and uncertainty of sensor measurements are also thoroughly investigated. Simulation results indicate that the uncertainty noise will affect the life calculation dramatically. Future works include:

- To design an optimal acceleration schedule under both deterministic and probability models;
- With the designed acceleration schedule and the probability life model, a better specification of the signal to noise ratio for the sensors is needed.

- A better intelligent controller is preferred in order to reduce sensor noise effect with a desired probability of failure.

Name: **Joseph J. Christie**
Education: Ph.D., Organic Chemistry
University of Southern Mississippi

Permanent Position: Visiting Associate Professor, Chemistry
University of Toledo

Host Organization: Materials Division
Colleague: 5150/Michael A. Meador

Assignment:

Development of benzofuran-based charge transfer fluorescent dyes and their potential applications as biosensor materials.

Research Summary Submitted by Fellow:

Charge Transfer (CT) Dyes for Sensor Applications:

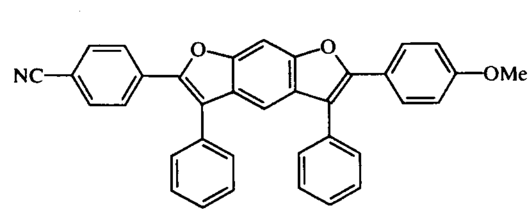
Earlier work done at NASA GRC by Michael A. Meador and team showed potential opportunities to commercialize the technology to produce certain types of CT dyes and to use them as sensors for biological and polymeric systems. As reported last year on the GRC web site Enzyme Systems Products company of Livermore, CA has expressed interest to license and commercialize the fluorescent dye technology.

In order to develop a viable commercial process to produce these charge transfer dyes two approaches have been developed during this summer.

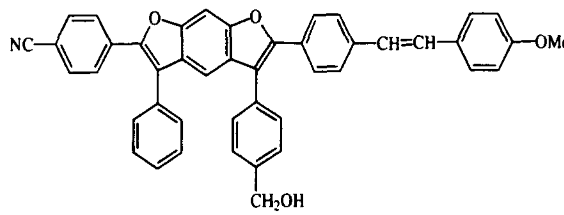
- One, is to employ a cost-effective non-photochemical method to cyclize the 1,3-dibenzyl ether(s) intermediate. Such an approach is also expected to give higher yields and cleaner products. Starting from resorcinol or 1,3-dihydroxybenzene, compounds of the structure(s) below have been made:

  $$\mathbf{ArCH_2\text{-}O\text{-}\mathit{m}\text{-}C_6H_4\text{-}O\text{-}\ CH_2Ar}$$

  Where, Ar has *para* substituents such as Br, CN, OMe etc.



- The second approach is to extend the versatility of these charge transfer dyes by structural modifications. In essence, the structural modification is aimed towards shifting the wavelength(s) of maximum absorption or λ_{max} to the visible to near Infrared region. The chemistry involves several synthetic strategies designed to extend the conjugation of the aromatic rings flanking the furan rings. Another aspect of the structural modification work is to incorporated a linker group such as $-CH_2OH$ or $-CH_2\ NH_2$ by which the dyes molecule can be tagged onto a protein molecule and thus be used as a bio-probe.



Target Molecule

With these goals, the following compounds were synthesized during the report period.

1. $Ph_3P^+CH_2$ *p*-C_6H_4Br Br^-, an intermediate to be used in structural modification work.
2. PhCOCHBrPh, a compound made by NBS bromination procedure, to optimize the reaction conditions, which will be applied to a similar reactions later in the work.
3.PhC *[-S-(CH₂)₃-S-*]-H, or the dithiane derivative of benzaldehyde, a key intermediate which will be used in a subsequent reaction.
4. Another approach that was attempted was a "crossed" benzoin condensation reaction between one mole each of p-bromobenzaldehyde and benzaldehyde, catalyzed by cyanide ion.
5. The Wittig Reaction: Compound $Ph_3P^+CH_2$ *p*-C_6H_4Br Br^-, was converted into its ylide (NaH and DMSO under nitrogen) , and condensed with PhCHO to obtain the alkene:

PhCH=CH-*p*-C_6H_4Br

This will be converted into its bromohydrin , PhCH(**OH**)CH**Br**- *p*-C_6H_4Br, by the electrophilic addition of **HOBr (using** NBS **in aqueous** conditions **).** Positive Br^+ ion is expected to preferentially attack the π-carbon atom bonded to the p-bromophenyl group since it has a greater electron density than the other carbon atom.
6. PhCH(**OH**)CH**Br**- *p*-C_6H_4Br, is etherfied with dihydropyran in *p*-TsOH and the protected compound, PhCH(**OTHP**)CH**Br**- *p*-C_6H_4Br is dibenzylated with the dianion of resorcinol , deprotected and cyclized to obtain the desired target molecule.

Conclusions:

Further work needs to be done to complete the synthesis of the CT dyes. After establishing the most convenient synthetic procedure, a host of these dyes can be made and their fluorescence spectra examined in a number of solvents. The spectral data will shed more light as to which is the best dye candidate to be used as a bio-probe.

Name:	**Pong P. Chu**
Education:	Ph.D., Electrical and Computer Engineering Iowa State University
Permanent Position:	Associate Professor, Electrical and Computer Engineering Cleveland State University
Host Organization:	Communications Technology Division
Colleague:	5650/Muli Kifle

Assignment:

General Purpose Self Re-Configurable Communication Processor

Future NASA science missions will require the use of satellite systems consisting of multiple sensor nodes autonomously responding and adapting to a dynamically changing space environment. Optimum utilization and configuration of spacecraft communications and navigation resources will be critical in meeting the demand of these stringent mission requirements. Self re-configurable hardware technology is an ideal solution to enable versatile adaptation of spacecraft system resources by dynamic allocation of unused hardware to perform new operations or to maintain functionality due to malfunctions or hardware faults. Automatic hardware reconfiguration can offer advantages of higher computation speeds and accuracy than the alternative software model download approach. Our research efforts focus on the development of a self re-configurable hardware architecture using evolutionary algorithms to meet the communications and data processing needs for a heterogeneous, multi-node satellite constellation. Self re-configurable communications and data processing techniques can enable tremendous hardware flexibility and maximum survivability of future science mission spacecraft

Tasks:

1. Conduct study/investigation on evolution-oriented re-configurable hardware architectures for communications and prepare a report on findings and recommendations (proposed approaches).

2. Assist in the development of self re-configurable communication processors (programmable modules) using genetic and evolutionary algorithms as advancement mechanism.

Research Summary Submitted by Fellow:

The major part of my work is to investigate the issues of using FPGA (Field Programmable Gate Array) devices to construct a dynamically reconfigurable communications system for small space spacecrafts. The major accomplishments are:

- Surveyed on relevant technologies, including space based Internet, wireless LAN, software radio, network processor and reconfigurable computer.

- Developed an extended layered networking model for the proposed communications system.
- Studied the feasibility of applying FPGA devices to implement the system.
- Suggested a platform-based design methodology to manage the reconfigurability and handle the complexity.
- Identified five platforms for future construction.

The completed effort and finding are documented in a paper, titled *Toward a Dynamically Reconfigurable Communications System for Small Spacecrafts*, which will be submitted to a relevant conference for publication.

Name: **Karen E. Crosby**
Education: Ph.D., Mechanical Engineering
Louisiana State University

Permanent Position: Assistant Professor, Mechanical Engineering
Southern University

Host Organization: Materials Division
Colleague: 5120/David L. Ellis

Assignment:

Microstructure and Properties of Copper Alloys and Diamond/Copper Composites

A major effort is required to analyze the microstructures of both GRCop-84 (Cu-8 at.% Cr-4 at.% Nb) and diamond reinforced copper matrix composites. The effort will directly contribute to the Space Launch Initiative (RLV 2nd Generation) and RLV 3rd Generation program objectives. The efforts during the summer of 2002 will concentrate on the optical and Scanning Electron Microscope (SEM) examination of the grain size and morphology.

For GRCop-84, a variety of specimens with differing processing and thermal histories are available for examination. Each requires the determination of the average grain size and aspect ratio. The volume fraction of Cr_2Nb also requires measurement. Following measurement, the changes observed will be correlated to the yield strength to determine of a Hall-Petch type of relationship exists.

Diamond reinforced copper matrix composites represent a new class of high thermal conductivity materials. Basic metallography is required to determine the soundness of the castings, the distribution of the diamond particulate and the thickness of the coatings on the diamond. A significant technical challenge exists in determining a suitable polishing technique to prepare the composites for metallographic examination. Work on this project is contingent on receipt of the samples from the manufacturer; material delivery is anticipated in June 2002.

Research Summary Submitted by Fellow:

Grain Size Distribution and Property Relationships

INTRODUCTION

GRCop-84 is a Cu-8at%Cr-4at%Nb alloy that is strengthened mainly by Cr_2Nb precipitates. The fine grain size of this alloy is also a source of strengthening. It is of interest for this study to determine the Hall-Petch relationship between strength and grain size and the contribution of grain boundaries to overall strengthening. Also, the grain size-thermal property relationship will be quantified. SEM analysis of GRCop-84 samples processed by extrusion and HIPing was performed to determine the grain size distribution. The grain structure of GRCop-84 has a size distribution average of 2.3 to 2.6 microns in the transverse and longitudinal extruded directions. The average grain size is slightly larger for the HIPped samples.

PROCEDURE

Microscopy was performed using the JEOL 840A SEM. Micrographs of each sample type were taken of one to two specimens at several randomly chosen places. The images were captured digitally on the computer connected to the microscope.

The stored images were analyzed using SigmaScan software. Individual grain boundaries were traced using a Wacom electronic tablet and pen. SigmaScan was configured to record the major and minor axis lengths of each grain measured. The perimeter and area of each grain were also recorded. Using this data, SigmaScan will calculate the shape factor and compactness, reciprocal measures of the equiaxial nature of each measured grain. 242 grains were measured in the transverse direction, 142 grains were measured in the longitudinal direction, and 60 grains were measured for the HIPped samples.

RESULTS

An example of the micrographs that were taken is shown in Figure 1. Figure 2 shows the grain size distribution histograms (calculated using Excel) of the three sample types with an overlay of the shape factor calculated data. PeakFit software was used to fit the measured grain size distribution to an equation for each sample type/orientation. The data shows a normal distribution. The fitted curves are shown in Figure 3. Table 1 summarizes the statistical information for the fitted grain size distribution curves. The transverse and HIPped have a Gaussian distribution while the longitudinal is log normal.

DISCUSSION

Grain Size Determination

The extruded specimens were sectioned from a bar with a cross section that was reduced at a 36:1 ratio. In the absence of recrystallization, one would expect to see extremely long grains with a similar aspect ratio. Dynamic recrystallization can occur during the hot extrusion process. The micrographs of the transverse and longitudinal extruded samples show slightly elongated grains, but the elongation is far from the reduction ratio. The micrographs and the histograms/distribution curves show that the average grain size is centered around 2.3 μm in the transverse direction and around 2.6 μm in the longitudinal direction—roughly within 12% of each other. This supports that recrystallization is significant, resulting in a considerable amount of equiaxed or nearly equiaxed grains. The grain size distribution of the HIPped samples is centered close to 3 μm. It should be noted that these average values indicate the center of the distribution peak(s) and not the arithmetic mean of the measured values. A linear fit of the shape factor data consistently decreases as the major grain diameter increases.

It is likely that there was some bias towards the larger grains during the measurement. The smaller grains were more difficult to see because precipitates obstructed them and it was easier to see the larger grains. However, because the distribution of grain sizes generally fits normal distributions, this should be adequately compensated for within the fitted distribution curve.

Grain Size and Properties

Mechanical and thermal properties of GRCop-84 have been measured previously. The contribution of the grain size, *d*, to the alloy properties may be calculated using the Hall-Petch relationship ($\sigma_y = \sigma_o + k_y d^{-1/2}$) with the material constants σ_o and k_y equal to 26 MPa and 0.16 MPa$\sqrt{m}$ for pure copper.

Several methods were considered for estimating the grain size for calculating yield strength. The mode, or most frequent value in the histogram for the measured data, the mode of the fitted data, or a weighted sum calculated by multiplying the histogram frequency percentage by the corresponding grain size. The σ_y estimates for each are presented in Table 2 for the extruded data. Table 2 also indicates the contribution of the grain boundaries to strengthening as a percentage of the offset yield strength.

CONCLUSIONS

It may be concluded that the recrystallization of the material is significant due to the fact that the majority of the grains fall within the same major diameter as shown by the histogram information. There is some skew of the data toward larger grains, however, the percentage of those large grains is relatively small. Therefore, the influence of the larger grain on the mechanical properties should be minimal.

Depending on the method used to estimate the grain size, the contribution of the grain boundaries is approximately 50-60% of the estimated offset yield strength. This is in line with findings reported by Anderson (2000) who stated that grain boundary strengthening accounts for nearly 60% of strengthening in Cu-8 Cr-4 Nb while the remaining strengthening comes from the precipitates due to an Orowan mechanism.

Figure 1. SEM micrograph of GRCop-84, 5000X (microscope mag). Longitudinal direction

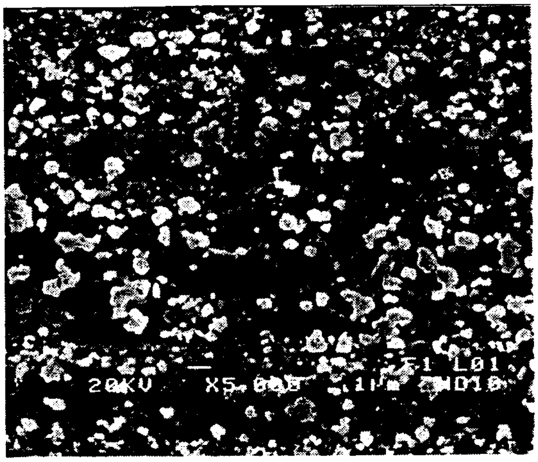


Figure 2. Grain Size Frequency Distribution

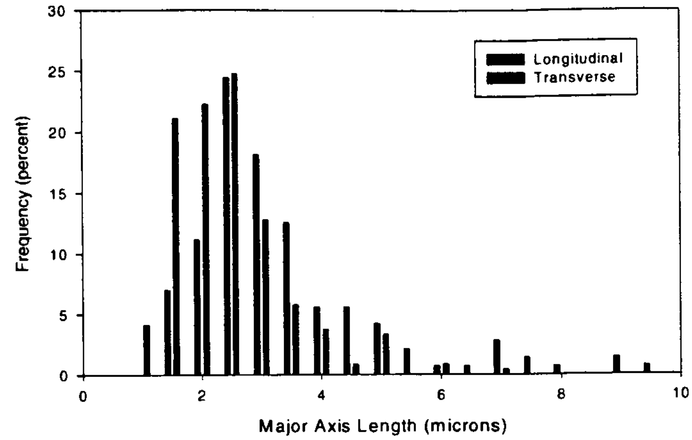


Figure 3. Fitted Grain Size Distribution

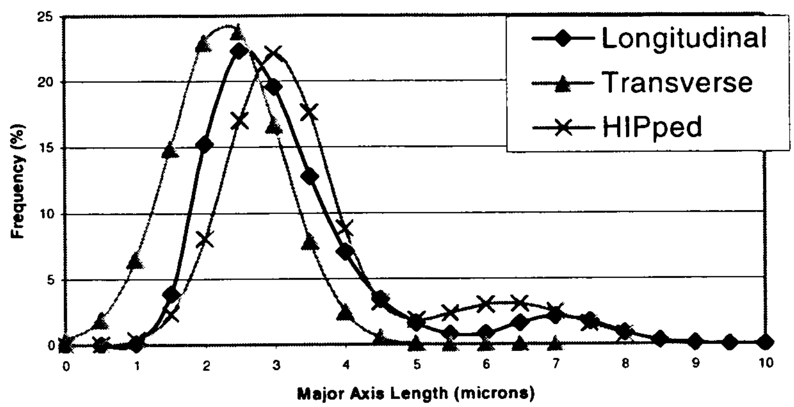


Table 1. Curve fit statistics and equation parameters

			Extruded		HIPped
			Transverse	Longitudinal	
Fit statistics	r^2		0.92820988	0.94206373	0.70846634
	Std. error		2.60122412	1.85500499	4.13486060
Fit Equation parameters	Peak 1	a_0	24.6088882	22.4672916	22.0873442
		a_1	2.29812490	2.57762754	3.01583531
		a_2	0.79508931	0.28824809	0.71491478
	Peak 2	a_0	---	2.11053709	3.13458932
		a_1	---	7.04463533	6.29905985
		a_2	---	0.09651454	1.03024431

Table 2. Yield strength estimates using Hall-Petch relationship and contribution to experimental values.

		LONG			TRANS		
		Measured value	Log Normal Fit Curve	Weighted	Measured value	Log Normal Fit Curve	Weighted
		2.5	2.58	3.24	2.5	2.3	2.3
	σ_y (Eqn. A5)=	127.1929	125.6116	114.8889	127.1929	131.5009	131.5009
σ_y^* (MPa)	LCL** = 210	60.6%	59.8%	54.7%	60.6%	62.6%	62.6%
	model† = 230	55.3%	54.6%	50.0%	55.3%	57.2%	57.2%

* experimental value
** LCL = 95% lower confidence limit
†Regression model

Name: **Asuquo B. Ebiana**
Education: Ph.D., Mechanical Engineering
Michigan State University

Permanent Position: Associate Professor, Mechanical Engineering
Cleveland State University

Host Organization: Power and On-Board Propulsion Technology Division
Colleague: 5490/Roy C. Tew, Jr.

Assignment:

Stirling Engine Thermodynamic Analysis

First Option: Assuming adequate Stirling engine data is available by the beginning of his tenure, Professor Ebiana will continue the task he started last summer of comparing predictions of the Sage Thermodynamic Model of the TDC 55 We Stirling engine to engine data taken at the Glenn Research Center. Last summer we found that the data needed to make a comparison was inadequate. Since that time an effort has been underway to upgrade instrumentation and measurements. If that is complete in time, we will attempt to make a careful comparison of the Sage Model predictions and the data.

Second Option: (Likely to require only part of the summer): One of Professor Ebiana's master's students at Cleveland State University is currently working on converting a Sage Thermodynamic Model of the CSUmod "paper engine" (a scaled version of the TDC 55We), to have the capability of predicting motions of piston and displacer via spring-mass-damper models of the piston motions, along with predicting the thermodynamic performance of the engine. Such a model would be useful in predicting the effect of certain changes in engine operational conditions on engine performance, including changes in piston motions (for example, degradation of hot end temperature and changes in displacer/cylinder gap over the life of an engine mission). Once we get this completed CSUmod model at GRC, we will need to convert it to model the TDC 55We engine. Professor Ebiana will be asked to help with this conversion, if time permits.

Third Option: If the first option does not "work out", and the second option is completed in relatively short order, we will do some work with the CFD-ACE computational fluid dynamics code related to multi-dimensional modeling of Stirling engines. I am currently using this code to model an MIT test rig (which includes a piston/cylinder and attached heat exchanger) and compare it with test data. Once this is done, additional tasks will be undertaken toward developing a complete model of a Stirling engine, to complement and assist ongoing work via a NASA grant at Cleveland State University with the goal of developing a complete multi-dimensional Stirling engine model. If time permits, Professor Ebiana will assist with some CFD-ACE code modeling related to development of a complete Stirling engine model.

Research Summary Submitted by Fellow:

INTERNAL MEMORANDUM*
(Thermo-Mechanical Systems Branch)
Stirling Engine "Off-design" Thermodynamic Analysis

ACKNOWLEDGEMENT

My tour of duty here at NASA Glenn Research Center during these past two summers has been worthwhile, and the experience gained invaluable and very rewarding. I wish to express my sincere thanks to Richard Shaltens, Chief of the Thermo-Mechanical Systems Branch, for the opportunity to work and study in his branch and to Roy Tew, my NASA colleague, for being such a kind, caring and understanding colleague, teacher and mentor. Indeed everyone in the Thermo-Mechanical Systems branch has been very nice to me and the environment here has been a pleasant one to work in. Thank you all so very much.

ASSIGNMENTS

Three assignments were delineated at the start of my tour of duty this summer. Assignment #1 required me to continue work started last summer of comparing predictions of Sage thermodynamic model of the TDC 55 We Stirling engine with engine performance data measured at Glenn Research Center. Assignment #2 required me to develop an "off-design" Sage thermodynamic model of the TDC 55 We engine for predicting engine performance in response to changes in engine operational conditions. In assignment #3, I was to begin to learn how to use the CFD-ACE computational fluid dynamics code with a view towards having me assist with some code modeling related to the development of a complete CFD-ACE Stirling engine model.

ACCOMPLISHMENTS

Assignment #1

It was shown last summer that Sage over-predicted engine performance and that the engine data provided were inadequate and in some respects unreliable. Therefore continuation of work started last summer is contingent upon receiving adequate and reliable data. Because effort is still underway to upgrade instrumentation and measurements, attempt at a careful comparison of the Sage model predictions with reliable engine data is yet to be made.

Assignment #2

The development of an "off-design" Sage thermodynamic model of a scaled version of the TDC 55 We Stirling engine for predicting engine performance in response to changes in engine operational conditions is a current Master's thesis research focus of Mr. Rahul Pawar [1], one of my graduate students at Cleveland State University. Mr. Pawar has implemented a three-step "off-design" Sage model development strategy, employing spring-mass-damper models for the Stirling engine's power piston and displacer, to obtain Phase I, Phase II and Phase III Sage models. The combination of the Phase I and Phase II models yielded the Phase III model, the required "off-design"

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* A more detailed Internal Memorandum is being prepared for the Thermo-Mechanical Systems Branch.

Sage model, which places no constraints on the motions of the power piston and displacer.

To obtain the "off-design" Sage model of the full-scale TDC 55 We engine, Mr. Pawar's Phase I, Phase II and Phase III Sage models were each modified to reflect the corresponding full-scale Sage TDC 55 We engine input parameters, re-evaluated for spring constant and damping coefficient values and re-validated. The Phase II and Phase III models needed special attention because of the electromagnetic force imposed by the linear alternator on the power piston. This force needs to be accurately represented in order to achieve confidence in the Sage model. Tew [2] and Regan [3,4], both NASA colleagues, have investigated the feasibility of incorporating an alternator force model into the simulation model of the free-piston Stirling engine. There appears to be a need for a major improvement in the verification or updating of the initial representation of the alternator force suggested by Tew and Regan.

An "off-design" Sage thermodynamic model of the TDC 55 We engine was successfully accomplished. Piston motion and thermodynamic performance predictions of the model correlated well with the reference "design" Sage model to within 0.08% error (see Table 1).

Examination of engine sensitivity to changes in heater temperature (see Figure 1) shows a decrease in the power piston/displacer amplitudes (after a slight initial increase) and engine power and efficiency with degradation of heater temperature. However, the phase angle difference increases with degradation of heater temperature, the implication of which is not presently clear. It is further observed that the pistons' maximum amplitudes are registered at different temperatures (870 K for the power piston and 880 K for the displacer) with the rate of change of amplitude with respect to temperature being more gradual for the displacer than for the power piston.

Assignment #3

The CFD-ACE computational fluid dynamics code provides an integrated grid generation module, a graphical user interface for preparation of the model, a computational solver for performing the simulation, and an interactive visualization program for examination and analysis of the simulation results. My familiarization with the code is a continuing process. I have already achieved some level of confidence in my ability to create a model using the code.

CONCLUSION

The capability to use an "off-design" Sage model of the TDC 55 We engine to match the reference constrained motion case has been successfully demonstrated with excellent piston motion and thermodynamic predictions to within 0.08%. Results of sensitivity studies show an eventual decrease in piston amplitude, increase in the phase angle difference and decrease in engine power and efficiency with degradation in heater temperature. Major improvement needed is the verification or updating of the initial representation of alternator force on the power piston.

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3. T. Regan, "Incorporation of the Maxwell 3-D Alternator Model into the Simulation Model of the FPSE". Sest, Inc., Deliverable No. 1, Contract No. NAS3-00170 Task Order No. 22.
4. T. Regan, Personal Communication.

Table 1. Design vs. "Off-Design" Sage Model Thermodynamic Performance Predictions

Thermodynamic Parameters	Design Sage Model (DSM) of TDC 55 We Stirling Engine	"Off-Design" Sage Model (ODSM) (Phase III)	% Error |(DSM-ODSM)/DSM x100|
Expansion Space PV Power (W)	160.50	160.50	0.00
Compression Space PV Power (W)	-90.05	-90.06	0.01
Total PV Power (W)	70.45	70.44	0.01
Electrical Power (W)	54.08	54.04	0.07
Total Heat Input Rate (W)	204.90	204.90	0.00
Overall Efficiency (%)	26.39	26.37	0.08

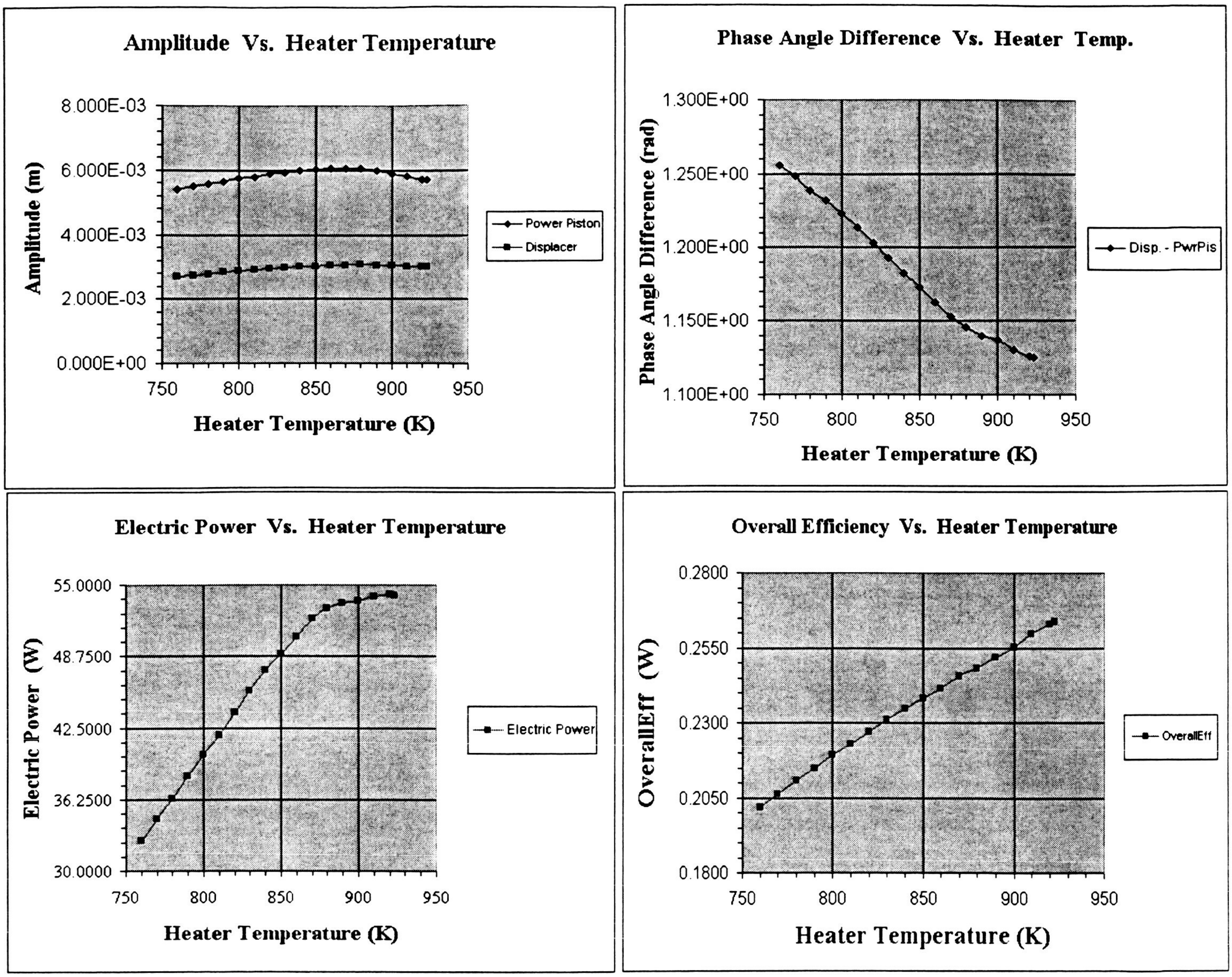

Figure 1. Sensitivity to Heater Temperature

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Texas Technical University

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Texas Technical University

Host Organization: Structures and Acoustics Division
Colleague: 5920/Noel N. Nemeth

Assignment:

Development of Testing Methodologies for the Mechanical Properties of MEMS

This effort is to investigate and design testing strategies to determine the mechanical properties of MicroElectroMechanical Systems (MEMS) as well as investigate the development of a MEMS Probabilistic Design Methodology (PDM). One item of potential interest is the design of a test for the Weibull size effect in pressure membranes. The Weibull size effect is a consequence of a stochastic strength response predicted from the Weibull distribution. Confirming that MEMS strength is controlled by the Weibull distribution will enable the development of a probabilistic design methodology for MEMS - similar to the GRC developed CARES/Life program for bulk ceramics. Another potential item of interest is analysis and modeling of material interfaces for strength as well as developing a strategy to handle stress singularities at sharp corners, filets, and material interfaces. Also of interest is development of testing strategies for mechanical properties such as Young's Modulus and Poisson's ratio as a function of temperature. The ultimate objective of this effort is to further develop and verify the ability of the Ceramics Analysis and Reliability Evaluation of Structures/Life (CARES/Life) code to predict the time-dependent reliability of MEMS structures subjected to multiple transient loads.

Research Summary Submitted by Fellow:

1. Introduction

This summer my research was centered on the notion of using the Weibull theory for singularities due to material interfaces. On contacting industry, I did establish that this is an important problem for a broad range of industries that deal with reliability predictions for structures with material interfaces. Furthermore, it was also established that currently there are limited unified approaches to solving this problem. My major accomplishments this summer, while at the NASA Glenn Research Center (GRC), include (1) an invited seminar, (2) literature review, review paper, and formulating potential strategies to attack this problem, and (3) a proposal submission to a federal agency regarding this topic.

2. Invited Seminar

A talk entitled "Biaxial testing of MEMS specimens" was presented as part of an invited seminar at the Sensors and Electronics Technology Branch at GRC. The talk focused on my current work in the area of Microelectromechanical Systems (MEMS) testing and probabilistic design. Some of the results presented were from some of my earlier work published in journal and conference proceedings. The motivation of this part of my research is to enhance the reliability and design of MEMS structures by an efficient extraction of mechanical properties. The talked covered MEMS testing, moiré hole method problem, biaxial testing, probabilistic design, singularities. The new concepts introduced were using the moiré hole method in a novel biaxial tester for MEMS specimens.

3. Review Paper

A review paper entitled "Approaches for Weibull theory for interface singularity" has been commenced. The related literature on the subject was critically reviewed. A majority of the paper is completed. Sixty-five pertinent references have already been included. Elements of the paper will be completed at Texas Tech University (TTU) before the submission to a journal for possible publication. The review paper addresses seven sub topics, namely, (1) singularity, (2) methods for interface singularity, (3) size effect, (4) Weibull theory, (5) Weibull failure theory for singularities, (6) strategies for Weibull failure theory for singularities, and (7) example problems. All these sub topics are directly related to the issue of using Weibull theory for interface singularity.

The statistical theory that is most widely used in the application of size effect to materials is that originally proposed by Weibull. Weibull theory indicates that there is a relationship between the degree of variability of strength and the magnitude of the size effect. It has been advocated that in the presence of singularity the conventional Weibull theory tends to overestimate the failure probability. This effect is more pronounced for high values of the Weibull exponent and is related to the fact that the critical flaw size is underestimated for flaws in the vicinity of the singularity point. As previously noted, there is a need to develop a more rigorous methodology of the Weibull theory to address singularity issues since there is a whole class of engineering problems that need to be addressed. These engineering problems include: bulge test for MEMS films and wafer bonds, structures with sharp notches; thin-film coatings and plating, laminated microelectronics packaging, and ceramic to metal joints. Currently, there are only two published approaches for Weibull theory with interface singularity, namely, length scale method and weight function method. The length scale method is based on the classical technique for accommodating discontinuities in a finite element solution by the introduction of length scale. In the weight function method the stress gradient due to the stress singularity is accounted for using weight functions. Both of these methods still need to be extensively verified experimentally.

In the review paper, potential strategies for extending Weibull theory for handling singularities will be outlined. Further work on the application and verification of the methodology will be left for future work.

4. Proposal

A proposal entitled "Probabilistic design and testing of MEMS" was submitted to the National Science Foundation (NSF). The proposal requested for an amount of $400,000 for 60 months. Elements of the proposal were developed out of the research assignment during this summer at GRC. The summary of the proposal submitted is follows:

With MEMS entering the mass production phase, issues relating to reliability have to be addressed. Analysts and designers are confronted with numerous engineering uncertainties and product variability. One way of addressing uncertainties and variability is through the systematic application of probabilistic design and testing. The advantage of probabilistic design is that the trade-off in material selection between high strength and low scatter can be integrated into the design process. Since the testing of MEMS takes place at the same relative, but not identical magnitude of scale as the devices, the size effect has to be also addressed. The statistical theory that is most widely used in the application of size effect to materials is that originally proposed by Weibull.

MEMS often contain numerous multimaterial interface corners. They arise as an inevitable byproduct of the many bonding and encapsulation technologies that are used for microassembly and packaging. Additionally, in MEMS fabrication, the resulting structures contain sharp re-entrant corners. Both the interface corner and the re-entrant corners create stress singularities. Although the deterministic aspects of these singularities have been studied, the probabilistic aspect of singularities in MEMS has not been adequately addressed in the literature.

To verify the theoretical probabilistic approaches developed, MEMS testing will be performed. A novel biaxial tester based on the moiré hole method will provide for the extraction of the material properties and residual stresses. In the proposed study the tester will be refitted for use in the vacuum chamber of the scanning electron microscope (SEM). Specifically, electron beam moiré (e-beam moiré) will be introduced. The experimental technique of e-beam moiré is a relatively new member of the family of moiré methods. E-beam moiré avoids the limits imposed on optical methods of moiré by the wavelength of light. The reference grating will be produced by the raster scanning motion of the electron beam in the chamber of the SEM. The specimen gratings will be produced using the electron lithography. The tester based on the e-beam moiré will be used to extract the stresses at the singularity of a MEMS specimen, which will be compared with stress values obtained from the proposed theoretical methodology. Thus, the theoretical results will be verified experimentally.

Thus, the proposed research plan to NSF puts forth an integrated education and research approach that has as its objective to develop probabilistic approaches for singularities in MEMS and verify the theoretical results with a novel tester based on e-beam moiré. The research plan identifies and establishes collaboration between disciplines and with government partners, specifically GRC.

5. Future Work

The future work involves further development of the methodologies proposed in the review paper, specifically, the extension of the Weibull Theory in problems involving singularities due to material interfaces. Additionally, the possibility of joint preparation of proposals to support future research at TTU or at GRC has been discussed.

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Permanent Position: Associate Professor, Composite Materials Engineering
Winona State University

Host Organization: Materials Division
Colleague: 5130/Narottam P. Bansal

Assignment:

Ceramic Materials for High-Temperature Coatings

The research project during this summer will consist of, but not limited to, the following:

a) Identify refractory oxide systems for 3000F thermal and environmental barrier coatings applications

b) Synthesize the oxide powders identified in (a)

c) Fabricate bulk ceramic specimens by hot pressing/sintering

d) Measure physical properties such as density, CTE, thermal conductivity, phases, etc.

e) Characterize chemical stability of the oxides to 3000F in combustion environment

Research Summary Submitted by Fellow:

Synthesis and Characterization of Multi-Components Ceramic Oxides for Coating Application

Thermal barrier coatings (TBCs) have been extensively used for the thermal protection of hot-section components in gas turbine engines and power generators. Lanthanum zirconate of composition $La_2Zr_2O_7$ is found to be a promising TBC because of its very low thermal conductivity and excellent thermal shock resistance. The thermal properties of this coating are expected to improve by addition of doping elements that reduce thermal conductivity and change the thermal expansion coefficient. Reduction of thermal expansion mismatch can be achieved by fabrication of graded coatings.

This study is focused on synthesis, processing, and characterization of $La_2Zr_2O_7$ and the Gd and Yb doped compounds as: $La_{(2-x)}Gd_xZr_2O_7$, and $La_{(2-x)}Yb_xZr_2O_7$ where x is X= 0, 0.1, 0.2, 0.3, 0.4, 0.5, and $La_{1.7}Gd_{0.15}Yb_{0.15}Zr_2O_7$. The synthesis methods were:

1. Solid State Powder Processing
   - Hot press
   - Cold pressed sintering

2. Sol-gel method
   - Hot press
   - Cold pressed sintering

3. Combustion synthesis

The as synthesized reaction products and the heat-treated samples were characterized by X-ray diffraction, scanning electron microscope, and thermal analysis methods. The following is a brief description of each method.

1. Solid-State Powder Processing

This method is based on solid-state diffusion of pressed oxide powders to form desired product over several hours at high temperatures. For production of lanthanum zirconate and lanthanum doped zirconates, stoichiometric amount of oxide of zirconium (ZrO_2), gadolinium (Gd_2O_3), ytterbium (Yb_2O_3), and oxide and hydroxide of lanthanum (La_2O_3 and $La(OH)_3$) were mixed in about 500 ml of water and ball milled for 24 hours. The water content of resulting slurry was evaporated at 90 °C and the mixed agglomerated powder was then ground and heat-treated at 1000 °C for 24 hours to out gas any possible contamination.

In order to evaluate the effect of doped elements, samples of mixed oxides with compositions of: $La_2Zr_2O_7$, $La_{1.7}Gd_{0.3}Zr_2O_7$, $La_{1.7}Yb_{0.3}Zr_2O_7$, and $La_{1.7}Gd_{0.15}Yb_{0.15}Zr_2O_7$ were prepared for fabrication into solid disks for thermal conductivity measurement. About 10 grams of each powder was hot-pressed in 25.4 mm. diameter die at 1600 °C and 4 KSI pressure for 3 or 4 hours in vacuum to produce disks of 2-3 mm thickness. Another set of solid disk samples were prepared by sintering of about 10 grams of pressed mixed powders in a 31 mm diameter die at 1600 °C for 12 and 24 hours.

2. Sol-gel Method

In this method the stoichiometric amounts of La, Gd, and Yb nitrates, oxynitrate or oxychloride of Zr, and citric acid ($HOC(CH_2COOH)_2COOH$) were mixed in water and the solution was heated at 90 °C for about 60 hours to evaporate water and form a condense gel. The precursors were the crystalline form of lanthanum nitrate ($La(NO_3)_3 \cdot 6H_2O$), zirconium oxynitrate ($ZrO(NO_3)_2 \cdot 2.3H_2O$), or zirconium oxychloride ($ZrOCl_2 \cdot 8H_2O$) as the sources of La and Zr. For Gd and Yb, nitrates of Gd and Yb were produced by addition of Gd_2O_3 and Yb_2O_3 to HNO_3.

The resulting concentrated yellowish clear gel was slowly heated (1 °C/minute) to 450 °C and held for 2 hours to remove volatile organic compounds and form related zirconate. The resulting black porous material was an amorphous zirconate and some charred organic material. Depending on the quantity of the gel prepared 2-5 hours of additional heat treatment of the crushed powder at 800 °C was required to burn off carbon residue. The resulting white powder was a partially crystalline zirconate. Additional heat-treatments at 1000, 1200, 1400, 1600 °C, converted the powder to the corresponding crystalline zirconate and some minor phases of related oxides. About 10 grams of the sol-derived white powder was also hot-pressed in 25.4 mm. diameter dies at 1600 °C and 4 KSI pressure for 4 hours in vacuum to produce disks of 2-3 mm thickness samples. Some more samples were produced by sintering of the cold pressed powders at 1600 °C for 12 and 24 hours.

3. Combustion Synthesis Method,

In this energy efficient highly reactive synthesis method, stoichiometric amounts of metal nitrate or oxynitrate were mixed with Glycine as the fuel to form a combustible mixture. Lanthanum nitrate ($La(NO_3)_3 \cdot 6 H_2O$) and zirconium oxynitrate ($ZrO(NO_3)_2.2.3H_2O$) were used as sources of La and Zr. For Gd and Yb doped zirconates, nitrate of Gd and Yb were produced by dissolving Gd_2O_3 and Yb_2O_3 in HNO_3. The exothermic reaction of nitrates with Glycine (NH_2CH_2COOH) creates a propagating flame at relatively low temperature 350 °C. The products formed were highly porous, low-density, and white to gray in color.

These combustion reactions produced submicrometer particles of zirconates. It was noticed that the fuel/oxidant ratio of the precursor has significant effect on the combustion rate and end product characteristics. The reaction period, phase composition, morphology, and surface area of some combustion reaction products were studied for several different compositions. It was observed that the initial fuel/oxidant ratio and nitric acid content of the precursor strongly influence the characteristics of the product obtained. For determination of the effect of phase change on these products, the white (or white/gray depending on the initial composition) combustion products were heated for two hours at 600, 800, 1000, 1200, 1400, 1600 °C.

Characterization of the Synthesized Ceramic Oxide

The composition and structural analysis of zirconate samples produced by all three methods was performed by the X-ray diffraction method. The effect of heat treatment on the chemical composition and crystallinity of the reaction products were also evaluated by the X-ray diffraction method. It was noticed that the sol-gel derived oxides were partially crystalline after heat treatment at 800 °C, the percent crystallinity and composition of the phases changed with heat treatment temperature. The same characteristic was also observed for the oxides obtained by the combustion method. Effect of heat treatment was also evaluated by thermal analysis method, including thermogravimetric and differential scanning calorimetry.

Name: **Patrick M. Flanagan**
Education: Ph.D., Mechanical Engineering
University of Cincinnati

Permanent Position: Associate Professor, Mechanical Engineering
Cleveland State University

Host Organization: Instrumentation and Controls Division
Colleague: 5520/John Lekki

Assignment:

Component Damage Detection Through Measurement of Vibrational Resonent Modes

The primary objective of this research is to study, both analytically and empirically if time allows, the efficacy of component damage detection through the measurement of vibrational resonant modes using fiber optic sensors. The development of cracks or small holes in a component will be correlated analytically to the spatial and frequency change in multiple mode shapes. An algorithm for damage detection through the monitoring of mode shapes for a simple plate will be derived. This algorithm will be based on the material characteristics of the plate, a model of damage from small holes and cracks, and also a model the mechanical/optical characteristics of the fiber optic sensors. If time allows, this algorithm with be tested by subtracting the damaged mode shape information from the original (good) mode shape for a simple plate instrumented with fiber optic sensors. Data from these tests will be used to develop a robust structural modification algorithm to predict the location and size of damage in a plate.

Research Summary Submitted by Fellow:

(We are deeply saddened to report that Professor Flanagan passed away while his research was still in progress.)

Name: **Rama S. R. Gorla**
Education: Ph.D., Mechanical Engineering
Hannover University, Germany

Permanent Position: Associate Professor, Manufacturing Engineering
Central State University

Host Organization: Research and Technology Directorate
Colleague: 5000/Isaiah M. Blankson

Assignment:

Professor Rama Gorla will work on the application of probabilistic methods to fluid structure interaction in the case of a turbine blade. The unsteady CFD will be coupled with the structural interaction. The TURBO Code available through NASA Glenn Research center will be used for this purpose. Proper grids will have to be generated for the turbine blade geometry given by the turbine heat transfer branch. Several unsteady aerothermodynamic cases will be analyzed and recommendations will be made for proper changes to the TURBO code to handle probabilistic computations. Thermodynamic probabilistic computations will be done for a selected turbine engine.

Research Summary Submitted by Fellow:

Probabilistic Analysis of a Gas Turbine System

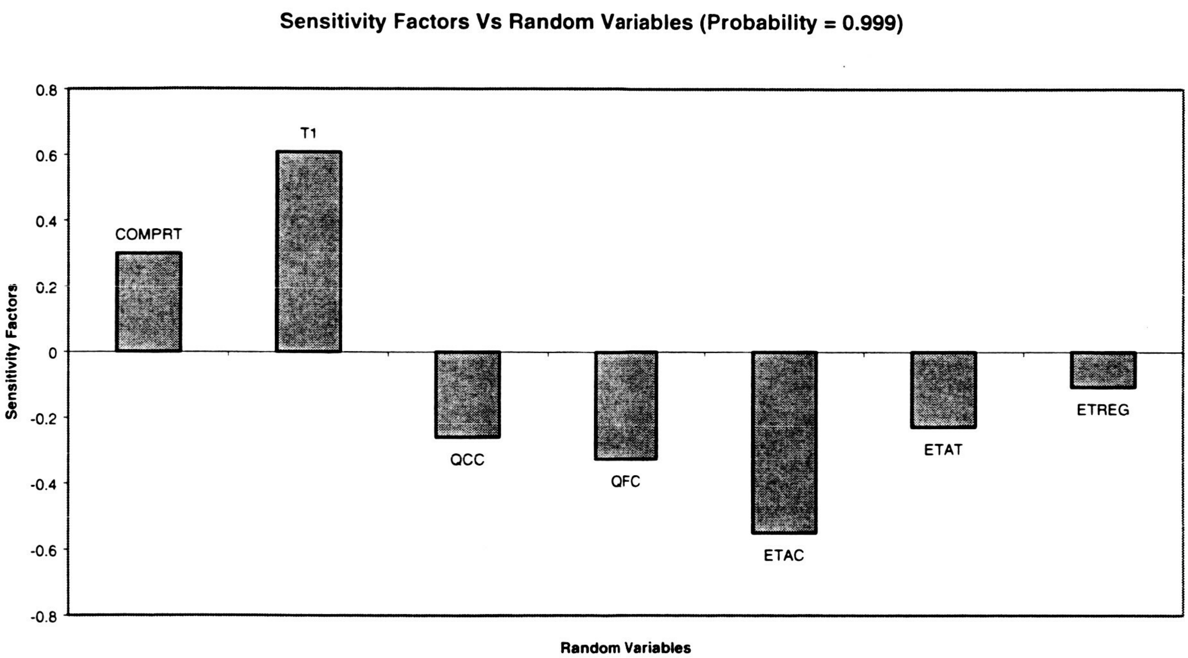
The majority of global power is generated from the consumption of fossil fuels, which represent a finite source. The rapid depletion of these fossil fuel resources remains one of the most important problems facing future world power generation. This means that the way in which power is generated will have to change over the next century. The power harnessed in the fossil fuels must be used more efficiently until renewable sources can be developed to meet a significant proportion of the increasing energy requirements. The option of developing new technology such as fuel cells, which exceed the maximum efficiencies of gas turbines seems very lucrative.

A fuel cell is a simple means of converting chemical energy to electricity without ignition combustion and it is promising to revolutionize the power generation industry. The chemical energy to the fuel cell is supplied on a continuous basis in the form of a fuel such as natural gas or synthesis gas while the oxidant is also supplied continuously. The fuel cell is not constrained by the Carnot efficiency and therefore higher conversion efficiencies are achievable with a fuel cell. The intermediate step of conversion into heat as in a heat engine is eliminated in a fuel cell.

As governments around the world strive to meet their escalating energy demands under increasing pressure from environmental issues, there exists a need for clean and efficient energy sources. Even the most advanced gas turbine cycles have difficulty in reaching a thermal efficiency of 40% and have NO_x emission problems due to their high operating temperatures. Stand-alone fuel cells have been manufactured with efficiencies of around 48% and produce negligible NO_x or SO_x and a reduced CO_2

owing to the increased thermal efficiency. Fuel cells can be incorporated into gas turbine cycles in order to produce efficiencies as high as 70%. The most suitable fuel cell for this application is solid oxide fuel cell (SOFC), which has the highest operating temperature.

The emergence of fuel cell systems and hybrid fuel cell systems requires the evolution of analysis strategies for evaluating thermodynamic performance. A gas turbine thermodynamic cycle integrated with a fuel cell was computationally simulated and probabilistically evaluated in view of the several uncertainties in the thermodynamic performance parameters. Cumulative distribution functions and sensitivity factors were computed for the overall thermal efficiency due to the thermodynamic random variables. These results can be used to quickly identify the most critical design variables in order to optimize the design and make it cost effective. The analysis leads to the selection of criteria for gas turbine health determination. The figure shown below indicates the sensitivity factors for thermal efficiency of the gas turbine power plant.



Name: **Marilyn Brown**
Status: Ph.D. Student
Institution: Cleveland State University

Accompanying Student under the direction of Professor Rama S. R. Gorla.

Research Summary Submitted by Student:

Optimization of Turbomachinery Blades

The purpose of the research I am involved in is to develop a technique to determine the maximum efficiency of a turbine blade by optimizing the geometry of the blade. For this to be accomplished a research tool called MSUTURBO was used. This is a computer program developed at Mississippi State University by Dr. J. P. Chen. MSUTURBO is a Fortran program that uses the Navier-Stokes equations for calculations of unsteady flow in turbomachinery. This program has the capability of simulating the flow over turbine and compressor blades then determining the pressures and temperatures generated across the blades surface. The complexity of the program itself is high. Turn around time for the batch computer job for the specific problem we are dealing with is approximately two weeks.

This summer was spent setting up the program and generating the data to run it. A lot of time was spent setting up and testing the program itself on various platforms. Sample runs were made to ensure that the program worked properly. After this was accomplished as a means of learning the program example case studies, included in the package, were run to show the various types of jobs the program is able to handle using steady and unsteady flow fields. Of the four cases studies the simplest case involves flow over a flat plate. This was a one dimensional problem that had a relatively short turnaround time. A two-dimensional case involved flow over a single blade row. Several successful runs were made using these example cases. The three-dimensional case shows flow over multiple blade rows. Each case comes with various sets of initial conditions and flow parameters.

For the problem being studied data had to be gathered and the geometry of the actual blade was determined. Grid files had to be developed that describe the geometry of the blades. The initial conditions and the parameters needed to run the program were determined. We are now in the position to run the actual case. From the data generated from MSUTURBO a finite element model will be made to determine the stresses on the blade due to the flow field. From there a probabilistic approach is to be developed to create varying geometries that will eventually converge to the optimal design.

Name: **Baha Jassemnejad**
Education: Ph.D., Solid State Physics
Oklahoma State University

Permanent Position: Professor, Physics & Engineering
University of Central Oklahoma

Host Organization: Instrumentation and Control Technology Division
Colleague: 5520/Arthur J. Decker

Assignment:

Design of a Nano-Technology Experiment for Optical Tweezers

Professor Jassemnejad will design an appropriate experiment to be performed using the optical tweezers for interrogation and manipulation of nano-devices. In the current configuration, we envision an optical-tweezers-manipulated tool that both senses and controls the manufacture of nano-structures. We are arranging for interferometric control of the forces and moments on the tool. We envision contact, evanescent-wave, or chemical interactions of the tool with the nano-structures. It is imperative that an experiment be designed that allows our approach to be tested on a realistic nano-structure. We feel that a person with a combination optics and solid-state-physics background is well qualified to design, and eventually participate in, such a test.

Research Summary Submitted by Fellow:

Laser Tweezers and Micro- and Nano-Manipulation of Objects

This brief summary report, which is for inclusion in the final report of the NASA Faculty Fellowship Program, describes the research project that I was involved in as a Faculty Fellow at NASA Glen Research Center during the summer of 2002. \

My project assignment was "Design of a Nano-Technology experiment for Optical Tweezers, " an experiment that would test the performance of an optical tweezers for noninvasive interrogation and manipulation of nano-devices. The major aim of developing this optical technology is to contribute to the NASA nano-technology research to support the Aerospace Propulsion and Power Base Research and Technology Program. While working on my experimental design, I engaged in the further development of the optical tweezers system that was originally developed by Arthur Decker (1) at the Optical Measurement Technology Branch. What follows is the description of the system that we have developed which allows us to perform certain measurements and experiments.

In general, optical tweezers uses a tightly focused laser beam in order to trap and manipulate particles. Invented by Ashkin in 1986 (2), optical tweezers has found applications in numerous areas in the past decade. Our optical tweezers configuration incorporates a spatial light modulator and an interferometer to produce a patterned optical tweezers and a single optical tweezers. As displayed in the diagram 1, a single beam, prior to entering an interferometer, is split into two beams with adjustable power ratio using a combination of a half wave plate (HWP_1) and a polarizer beam splitter cube (PBSC). One of the beams after reflection from the software controlled spatial light modulator forms a predetermined optical tweezers pattern. The other beam, whose polarization state is determined by the half wave plate (HWP_2) setting, after traversing the movable prism (RP) followed by reflection from the moveable mirror (M_1) can serve two purposes: When its polarization is orthogonal to the polarization of the pattern beam it serves as a single laser tweezers referred to as tool or probe beam. Its power is adjusted by the HWP_1 and its steering ability is accomplished through the time adjusted remote electronic control of the M_1. If its polarization is the same as that of the pattern beam, it will serve as a reference beam to interfere with the intensity of the pattern beam. The resultant interference pattern is controlled through the time adjusted remote electronic control of the prism (RP). The optical trap patterns and the single trap pattern are imaged, through the telescope formed by lenses L_3 and L_4, on the entrance people of a 100X 1.25NA oil immersion microscope objective that forms the laser tweezers. The image is detected by using a CCD camera.

Using this single configuration system, we were able to trap polystyrene spheres as small as ~ 900 nanometers (see figures 1.a and b). The unique feature of the tool beam enabled us to rapidly deliver the particles into and out of the laser tweezers pattern. We were able to interrogate and manipulate the particles in the tweezers pattern by bringing the tool tweezers beam, filled or not filled by a particle, near the pattern. The tool laser tweezers was able to trap up to four 10-micrometers particles and rapidly moving them. The interferometer control of the laser tweezers pattern was demonstrated at low spatial frequencies.

The unique capabilities of this system are envisioned to be for the manipulation of individual nano-particles as needed for a variety of nano-technology, such as the construction of nano-engineered structures for sensors or electronics. However, it can also potentially serve in a variety of applications including but not limiting to the following: physical and biological experiments, microscopic manufacturing, biomedical engineering, and scanning near-field optical microscopy.

Acknowledgement:
This project was sponsored through NASA Faculty Fellowship program, 2002. The author wants to thank: Arthur Decker for his serving as the NASA colleague and for his personal and professional interactions; Ken Weiland for his technical support; Mary Zeller for arranging 7training in the Atomic Force Microscopy by Phil Abel, and her professional guidance; and Carolyn Mercer for her support and facilitation.

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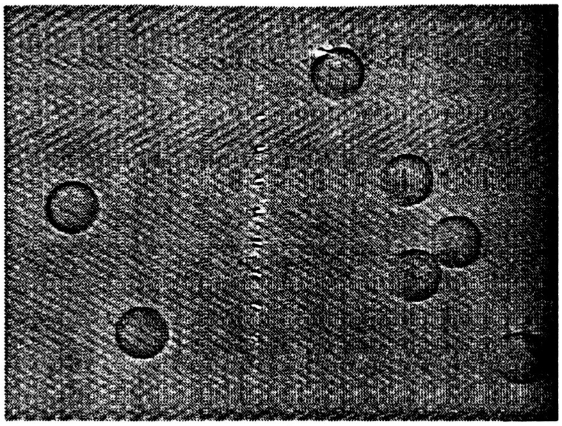

Figure 1.a. Laser tweezers pattern.

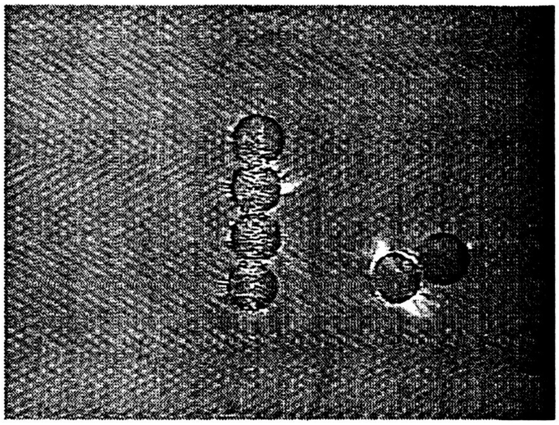

Figure 1.b. 10 micrometers particles trapped in the pattern.

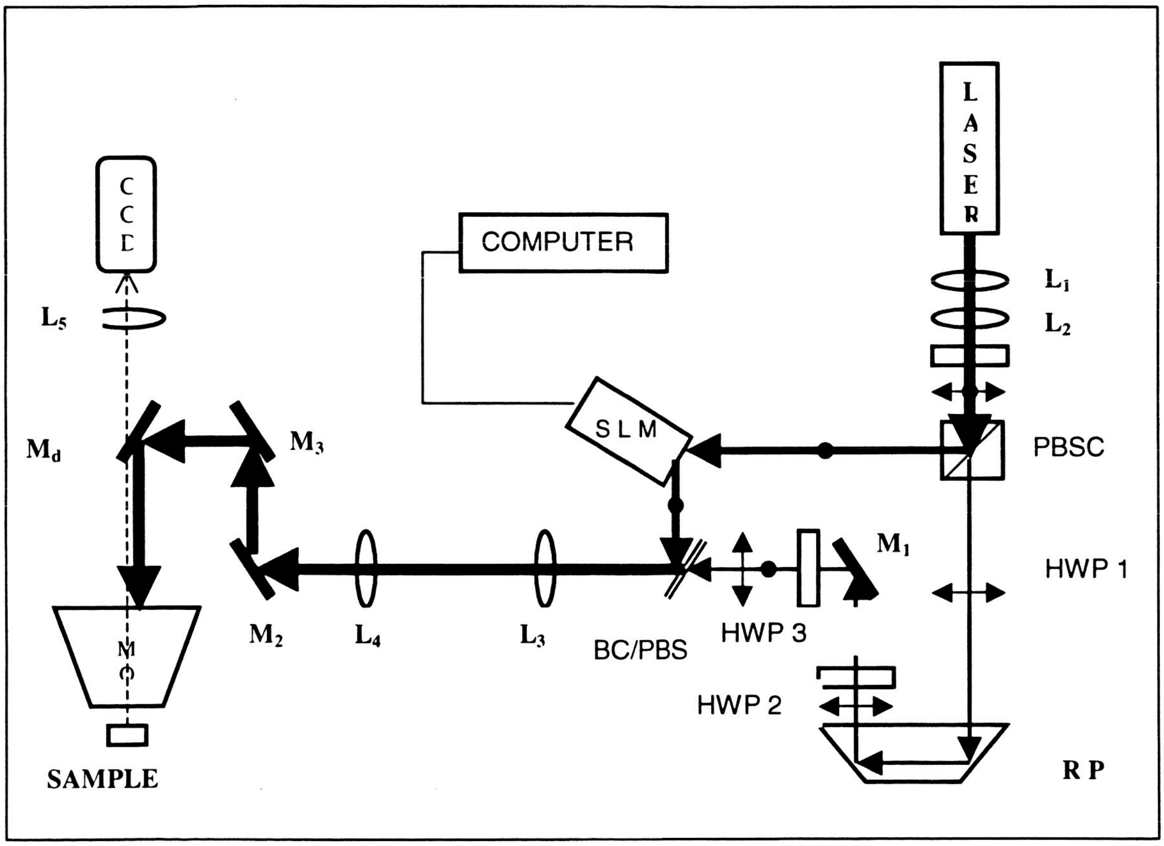

Diagram 1. Optical tweezers configuration for forming tweezers pattern and manipulating the particles therein.

Name: **Michael G. Jenkins**
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University of Washington

Permanent Position: Professor, Mechanical Engineering
University of Washington

Host Organization: Structures and Acoustics Division
Colleague: 5920/Jonathan A. Salem

Assignment:

Development of Probabilistic Continuum Damage Mechanics (PCDM) Methods for Ceramics

Given the relative newness of Continuum Damage Mechanics (CDM) as a branch of engineering mechanics, the application of CDM to monolithic and composite structural ceramics is in the embryonic stage. Nevertheless, the first step in the project is to assess the current state of the art for CDM and ceramics. Because the probabilistic, weakest link failure behavior of ceramics requires probabilistic design methodologies, the second step in the project is to propose and develop Probabilistic Continuum Damage Mechanics (PCDM) methods for ceramics. This step is highly innovative and novel because conventional CDM models to date have been deterministically based and, therefore, are not appropriate for ceramics (including ceramic composites). The final step in the project is to compare predictions of the PCDM methods to both deterministic CDM methods and empirical results. This step will validate the PCDM methods and should be relatively straight forward if existing test data are used.

Research Summary Submitted by Fellow:

The following summary report briefly summarizes my accomplishments during Summer 2002 under the NASA Faculty Fellowship Program with host, Jonathan Salem in the Life Prediction Branch at NASA Glenn Research Center.

Introduction

My original project statement, entitled "Probabilistic and Deterministic Damage Mechanics Applied to Monolithic and Composite Ceramics," was as follows:

Given the relative newness of continuum damage mechanics (CDM) as a branch of engineering mechanics, the application of CDM to monolithic and composite structural ceramics is in the embryonic stage. Nevertheless, the first step in the project is to assess the current state of the art for CDM and ceramics. Because the probabilistic, weakest link failure behaviour of ceramics requires probabilistic design methodologies, the second step of the project is to propose and develop probabilistic continuum damage mechanics (PCDM) methods for ceramics. This step is highly innovative and novel because conventional CDM models to date have been deterministically based and, therefore, are not appropriate for ceramics (including ceramic composites). The final step in the project is to compare predictions of the PCDM methods to both deterministic CDM methods and empirical results. This step will validate the PCDM methods and should be relatively straight forward if existing data are used.

Project Summary

Standards for Ceramics: Although the major goal of the project involved probabilistic damage mechanics, another important goal involved interacting with other NASA researchers in regard to standards for monolithic and composite ceramics. In this regard, CD-based summaries of the 40 standards for advanced ceramics under the jurisdiction of ASTM Committee C28 "Advanced Ceramics" (M. Jenkins, chair) were distributed to and discussed with selected ceramic researchers at NASA-GRC (M. Singh, D. Brewer, G. Morscher, and J. Salem). In addition to obtaining information relevant to initiating new efforts for ASTM standards for ceramics, two new draft NASA standards were developed as possible precursors to ASTM and/or ISO standards:

i) "Recommended Material Removal Processes for Advanced Ceramic Test Specimens"
ii) "Determination of Slow Crack Growth Parameters of Advanced Ceramics by Constant Stress Flexural Testing (Stress Rupture) at Ambient Temperature"

In addition, two presentations were prepared along with one publication on standards for ceramics

i) "Standards, Design Codes and Data Bases for CMCs: Where we are and where we need to be", by M. G. Jenkins for Turbine Engine Technology Symposium 2002, Dayton, Ohio, 09-12 September 2002 (presentation only)
ii) "Standardization Efforts for Mechanical Testing and Design of Advanced Ceramic Materials and Components," by J. A. Salem and M.G. Jenkins for 5th Conference on Aerospace Materials, Processes, and Environmental Technology, Huntsville, Alabama, 16-18 September 2002 (paper and presentation)

Damage Modeling: An overview of damage modeling for ceramic composites had been prepared at the end of 2001. This overview ("Damage Evolution and Damage Tolerance in Ceramic Matrix Composites: Empirical Measurements and Analytical/Numerical Modeling," M.G. Jenkins, Proceedings of the 10 th International Conference on Fracture, Elsevier, London, 2001) provided the basis for the start of the summer's research. As part of the research efforts, damage measurement methods for ceramic matrix composites (CMCs) were discussed with D. Brewer and G. Morscher. Unload/reload tensile test stress-strain curves for various types of melt-infiltrated CMCs were obtained for further analysis to extract damage information.

A damage-based macro code initially developed to drive a commercial finite element analysis (FEA) code (ANSYS™) using deterministic strength distributions for matrix and fibre elements and an element stress-based "birth and death" feature was modified to include probabilistic strength distributions for matrix and fibre elements. A major accomplishment was for this macro code to run successfully for a model of a CMC beam loaded in four-point flexure. The FEA results for deterministic and probabilistic macro code models were compared to previously measured experimental results for CMC beams tested in flexure. The results of the summer's research have been submitted for presentation and publication as "Probabilistic Damage Mechanics: Modeling and Interpretation Cumulative Failure in Ceramics and Composites" by M. G. Jenkins and J. A. Salem, 27th Annual Cocoa Beach Conference and Exhibition on Advanced Ceramics and Composites, Cocoa Beach, FL, 26-31 January 2003.

Figure 1 on the following page shows the flow chart of the macro for the FEA program. Figure 2 shows an illustration of the double meshed (matrix and fibre elements) FEA flexure beam model with a single set of nodes. Figures 3 and 4 compare the experimental force-displacement curves for the CMC loaded in four-point flexure to results from the deterministic and probabilistic damage macros, respectively. Finally, Figures 5 and 6 show examples of the final damage state (killed elements removed) for the matrix and fibre elements that resulted from one of the runs of the probabilistic damage macro. Note the lack of symmetry and consistency of the killed elements that one would expect for probabilistically distributed strengths of the elements in a uniaxial stress state.

Additional research work on the probabilistic damage macro for the FEA model includes the effect of mesh density, the effect of assumed boundary conditions, the effect of two and three dimensional assumption (i.e. plane stress vs. plane strain), effect of the nonlinear solution parameters, and other aspects.

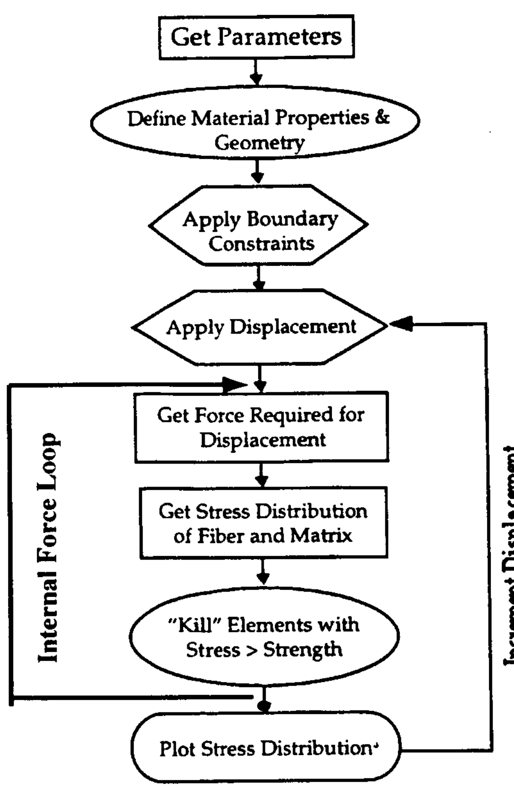


Figure 1 – Flow chart for macro code to simulate cumulative damage.

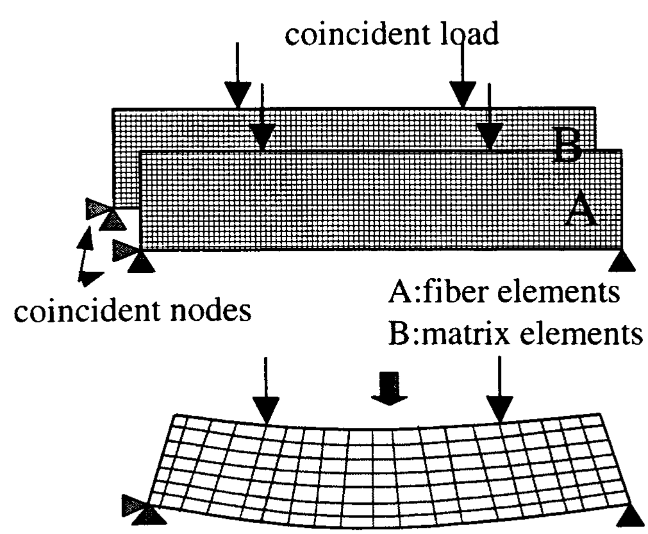


Figure 2 – Model of double meshed FEA beam in four-point flexure

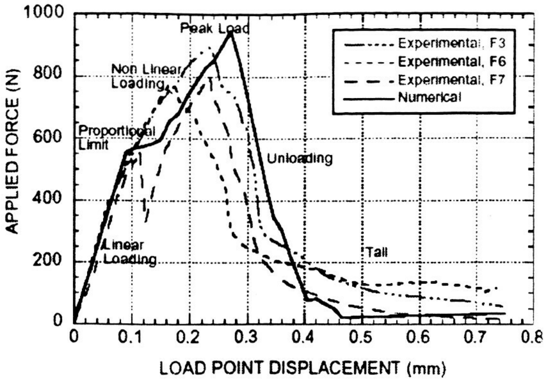


Figure 3 – Comparison of experimental results to deterministic strength FEA model

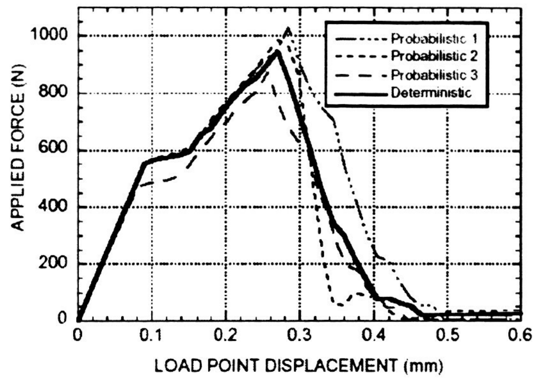
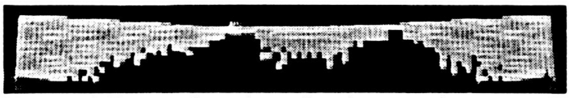
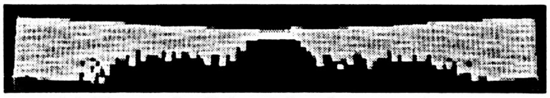


Figure 4 – Comparison of deterministic and probabilistic FEA models

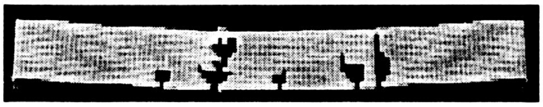


a) Example 1 (matrix elements)

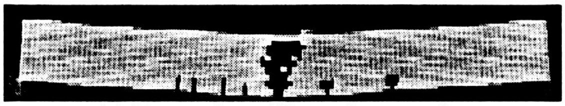


b) Example 2 (matrix elements)

Figure 5–Examples of "killed" matrix elements for a probabilistic FEA model



a) Example 1 (fibre elements)



b) Example 2 (fibre elements)

Figure 6–Examples of "killed" fibre elements for a probabilistic FEA model

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Assignment:

Development of Simulation Techniques/Tools for RF MEMS Devices

The objective of this research is to develop a robust, multi-domain numerical simulation tool that will help to improve our understanding of Micro-Electromechanical Systems (MEMS) behaviors and eventually enable optimal design of MEMS.

For Summer 2002, the Least Square Finite Element Method (LSFEM) will be used to analyze the instability point of an electrostatically actuated elastic structure such as a MEMS capacitor having a conducting beam clamped at both ends and suspended over a ground plane. When voltage is applied between the beam and the ground plane, the charges induced on the beam and the ground plane produce an attractive force between them causing the beam to bend toward the ground plane. At a critical voltage, called the pulled-in voltage, the linear elastic restoring force is overwhelmed by the nonlinear attractive force, and the beam collapses. The behavior of this electrostatically pulled-in beam is due to the coupling between electrostatic and mechanical forces. One of the goals of this study is to analyze the deformation of the beam for various design parameters such as beam dimensions as a function of pulled-in voltages with numerical simulation tool developed.

Research Summary Submitted by Fellow:

The Least-Squares Finite Element Method for MEMS Simulation

To reduce time in design of Micro-Electro-Mechanical System (MEMS) and allow for aggressive design strategies, it is necessary to develop simulation tools that will allow designers to test experiments in hours instead of months. One of the most challenging aspects of developing computer simulation tools for MEMS is the multi-domain nature of micro-electro-mechanical devices. Whereas electronic circuits function almost exclusively in the electrical domain, MEMS device operation transcends the boundaries among the thermal, fluid, electromagnetic, mechanical, and optical domains. The need for coupled solutions over several domains challenges the state of the art in numerical simulations.

The ultimate object of this research is to develop a robust, multi-domain numerical simulation tool that will help improve our understanding of MEMS behaviors, and eventually enable optimal design of MEMS. The least-squares finite element method

(LSFEM) has a unified mathematical and computational formulation for the numerical solution of all types of partial differential equations[1]. For this reason, the LSFEM is able to simulate multi-disciplinary problems, such as complicated interaction between structure stress, electrostatic or magnetic forces, and fluid tractions in MEMS. As the first step of this project, the LSFEM will be used to analyze the instability point of an electrostatically actuated elastic structure: a conducting plate clamped at both ends by dielectric supports, and suspended over a ground plane by a gap. When voltage is applied between the plate and the ground plane, the charges on the plate and the ground plane produce an attractive force between them, which causes the plate to bend towards the ground plane. At a critical voltage, called the pull-in voltage, the elastic restoring force is overwhelmed by the nonlinear attractive force, and the plate collapses. The behavior of this electrostatically pulled-in plate is due to the coupling between electrostatic and mechanical forces.

The partial differential equations governing the deformation of the thin elastic plate are written in the first-order deflection-slope-moment-shear force formulation including four compatibility conditions[2]. The plate is subject to the distributed electrostatic force

$$q = \frac{\varepsilon_0 V^2}{2e^2} \frac{1}{\left(1 - \frac{w}{e}\right)^2}$$

where ε_0 is the dielectric constant of the gap between the plate and the ground plane, V is the applied voltage, e is the gap and w is the deflection of the plate.
A capacitive RF switch used for array antennas has been modeled. The geometry of the plate is a $400\mu m \times 150\mu m$ rectangle with uniform thickness t = $1\mu m$. The material properties of polysilicon: the Young's modulus E = 160Gpa and the Poisson's rate μ = 0.22. The gap e = $2\mu m$ and ε_0=8.854×10^{-14}F/cm. The plate was analyzed with 200 bilinear elements. A plot of the center deflection with respect to the applied voltage is shown in Figure 1. From this figure we find that the pull-in voltage is 83.

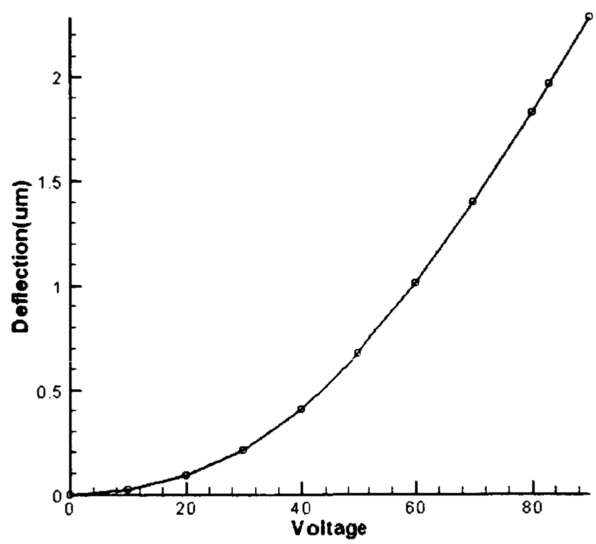

Figure 1. The center deflection vs. applied voltage for a plate actuator

For more precise simulation we have also developed the LSFEM based on large deformation theory of the thin plate.

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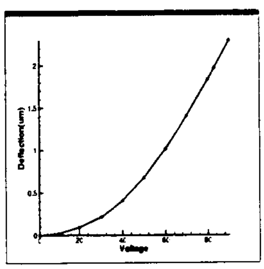

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Education: Ph.D., Metallurgical Engineering
University of Illinois - Urbana

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University of Florida

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Colleague: 5120/Ronald D. Noebe

Assignment:

High Temperature Shape Memory Alloys

Arc melted buttons of various NiTi-X alloys are being made as this is being written. Professor Kaufman will join our team in evaluating these alloys. Hands-on experimental work in mechanical testing (Instron), and microscopy (SEM, TEM) to evaluate the effects of alloying and processing on the microstructure and mechanical behavior of the alloys will be done.

Research Summary Submitted by Fellow:

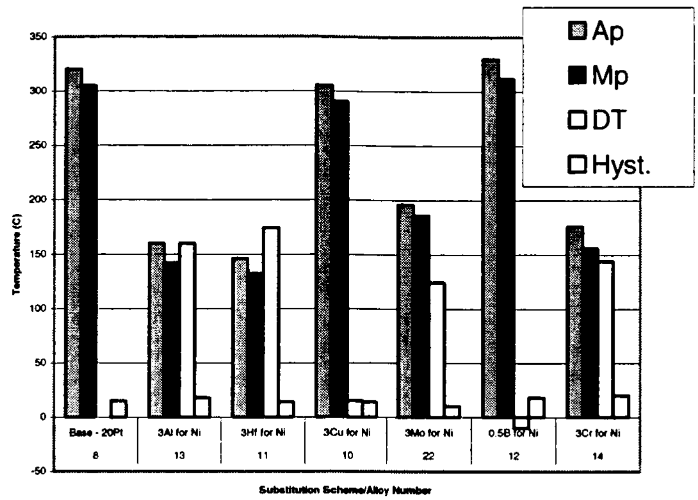
Preliminary Investigation of Ti-Ni-Pt-X Shape Memory Alloys for Higher Temperature Applications

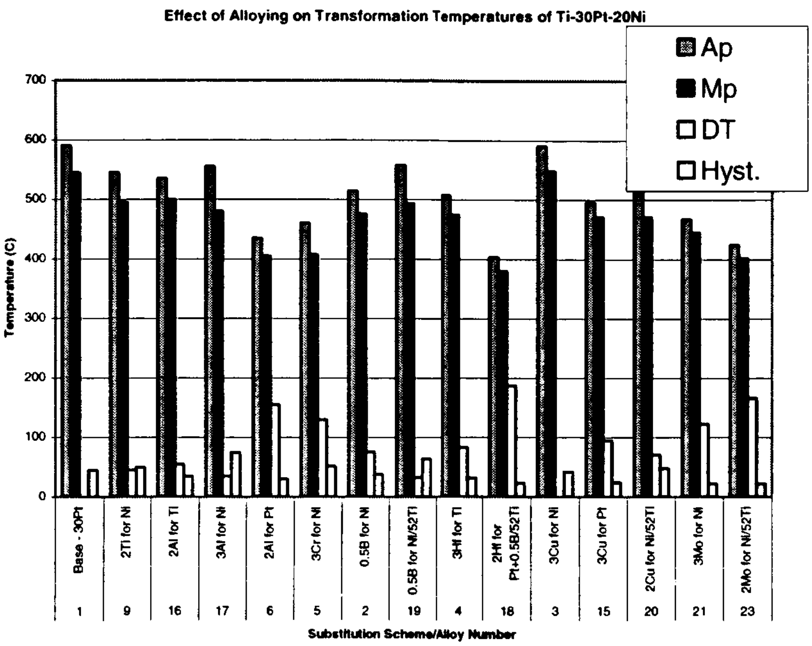
Twenty-three ternary, quaternary and quinary alloys based on the Ti-Ni-Pt ternary system were selected and prepared prior to my arrival. These alloys are being investigated to determine their suitability for high temperature applications such as automatic actuators, valves, etc. given that they have higher transformation temperatures than all of the other Nitinol-based shape memory alloys studied to date. Working closely with Drs. Ron Noebe and Anita Garg, who helped me in all aspects of this study, along with the oversight of Dr. Mike Nathal, we analyzed these arc-melted and "homogenized" buttons using optical microscopy, scanning and transmission electron microscopy, DSC, limited DTA, preliminary strain recovery and two-way training experiments and, most recently, preliminary oxidation tests (being performed by Ms. Tiffany Biles). The results of the various analyses are summarized in the following. We envision that there will be 1-3 papers published based on this work as well as some ongoing research and the University of Florida concerning this topic.

Are Melting and Composition Fluctuations – The densities of Ti, Ni and Pt are 4.5, 8.9 and 29.5 g/cc, respectively. Therefore, Pt is over 6X denser than Ti and over 3X heavier than Ni. When one arc melts a 50gm button of the base alloy Ti-30Pt-20Ni, the weights of the different species are 25.4Ti-62.1Pt-12.5N (in grams). This corresponds to volumes of 5.6cc of Ti, 2.1cc of Pt and 1.4cc of Ni. If you just add these together, you get 10.1 cc total. If we assume that the shape of the button is a hemisphere, the radius of the hemisphere for a 10.1cc volume would be $0.667^*pi^*r^3$ so that r=1.69cm which is about the right size as most of the slices are in this size range. Thus, if one sees an unmelted particle that is 2mm in diameter, if it is all Pt, it would correspond to a volume of .0042cc, which is 0.12gm of Pt. Since the total amount of Pt is 62.1gm, this would be a 0.2% drop in Pt and the alloy composition would change ever-so-slightly. This implies that you probably can "live with" a few unmelted particles although you wouldn't want to make this a goal.

By the way, the issue seems to be that the heavy Pt tends to drop towards the mush at the bottom of the molten region of the button. The evidence is that about 1/3 of the button is still solid during arc melting. When Sharon flips it over, it now sits at the 2/3 position where it readily falls to the new 1/3 position as soon as the lower melting point material surrounding it starts to melt. The evidence is that some alloying of the Pt frequently occurs, yet total dissolution of the Pt (or Pt-rich material) is still a challenge due to this density issue. It would be a bit like taking water with salt at the bottom and trying to melt the salt by heating the water on the top side and chilling the salt/water mixture on the bottom. Thus, the arc melting technique/protocol should be investigated systematically by flipping the samples over a different number of times and characterizing the amount of unmelted platinum. An alternative approach would be to use a high platinum Ni-Pt alloy.

Specific Results and Questions – All 23alloys were run by DSC and most have been characterized at least by SEM. Keep in mind that there are some challenges with slight differences in the actual vs. the aim compositions and the Chem Lab results should be referred to accordingly. The most significant finding is that the alloying elements tend to influence the transformation temperatures differently depending on the substitution scheme. The following graphs illustrate the transformation temperatures of the various alloys as a function of the substitution scheme. There was much ancillary data generated in support of these graphs but it is too much to present here. It will however be incorporated into the manuscripts that we intend to publish.





Summary of DSC data for the various alloys studied. A_p=austenite peak, M_p=martensite peak, DT=difference between austenite peaks of alloy vs. base, and Hyst=hysteresis.

Name: **<u>Walter M. Kocher</u>**
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Colleague: 0540/Daniel D. White

Assignment:

Pollution Prevention (P2) and a Real-Time Environmental Monitoring System (RTEMS)

Professor Kocher will be working on the research and development of Pollution Prevention (P2) opportunities and a Real-Time Environmental Monitoring System (RTEMS) at the NASA Glenn Research Center, as well as on the continuing development of a garnet abrasive recycling system. Environmental modeling and computer simulations, developing site-specific program modifications and applications, will also be included in his scope of work (specifics still to be determined).

A wide range of P2 opportunities will be investigated. Methodologies will be developed for conducting life-cycle analysis and sustainable design evaluations for NASA GRC. Several other P2 potential projects will be considered, and environmentally-friendly alternatives to existing operating conditions will be researched and analyzed for applications at GRC.

The RTEMS project entails the ongoing development of a monitoring system, which includes sensors, instruments, computer hardware and software, plus a data telemetry system. The environmental monitoring requirements address air emissions, wastewater, storm water, surface water, and noise issues. The pollution prevention measures and the RTEMS applications must also be developed to provide flexibility for significant additions and modifications to the site, meeting future environmental compliance requirements and parameter monitoring needs.

Research Summary Submitted by Fellow:

Dr. Kocher has been working on three new projects this summer, as well as supervising the continuations of two ongoing projects.

The creation and development of a Life Cycle Assessment (LCA) program at GRC was initiated this summer. Dr. Kocher developed LCA evaluation tools to be used by NASA researchers and project managers. He also authored a chapter for the GRC

Environmental Programs Manual (EPM) that establishes policies and procedures for applying life cycle assessment principles to facility operations. This plan does the following:

- Describes the status and current policy for sustainable design / life-cycle costing and assessment policy and requirements for GRC buildings, structures and facilities including the environmental, energy and water costs of construction, purchase, renovation, ownership, operations and maintenance
- Establishes life-cycle costing and assessment policy, procedures and requirements for all operations at GRC that are not addressed by the sustainable design policies, nor are they adequately addresses by the AP / EPP program.
- Promotes life-cycle assessment /accounting and sustainable design activities throughout the facility by all employees and contractors
- Delineates the roles and responsibilities of individuals, teams and organizations necessary to implement this program
- Establishes program metrics and evaluation procedures which relate the results of activities to the goals
- Supports EMS goals including resource allocation for cost effectiveness

A related project involved the establishment of the Affirmative Procurement / Environmentally Preferred Products (AP / EPP) program. This required the adaptation of life cycle principles to perform life cycle assessments of many off-the-shelf products. Working with a graduate student (Linda Sekura), Dr. Kocher developed detailed evaluation matrices (spreadsheets) and wrote detailed instructions for future product evaluators to prepare AP / EPP product lists. He also authored another EPM chapter that addressed the implementation of the AP / EPP program at GRC which will promote and facilitate the purchase of environmentally-friendly and recycled products at GRC. This plan does the following:

- Establishes criteria for affirmative procurement products and a life cycle costing and assessment process for evaluating potential EPP items. The selection process may be specific to categories of products (ie. general cleaning products), but will be uniformly applied to all products within each product category.
- Promotes the purchase of recycled and environmentally-friendly products throughout the facility by all employees and contractors
- Delineates the roles and responsibilities of individuals, teams and organizations necessary to implement this program.
- Establishes program metrics and evaluation procedures which relate the results of activities to the goals
- Supports EMS goals including resource allocation for cost effectiveness

Dr. Kocher has also lead a team (including graduate student Loreto Agdinaoay) that has been preparing a combined contingency plan for GRC dealing with several regulatory requirements. The traditional approach has been to write such plans separately to focus upon the specific requirements of a single law / regulation. This team has developed a means of combining such contingency plans so that they can be more effective at communicating the critical information to emergency response personnel without regard to a particular law – yet meeting the legal requirements of each of the relevant laws / regulations.

The ongoing projects include the continuing development of a Real-Time Environmental Monitoring System (RTEMS) at the NASA Glenn Research Center. Dr. Kocher has served as the project director for more than 3 years. The RTEMS project entails the ongoing development of a monitoring system which includes sensors, instruments, computer hardware and software, plus a data telemetry system. The environmental monitoring requirements address air emissions, wastewater, storm water, surface water, and noise issues. The bench-scale unit was successfully demonstrated near the end of the summer – the next phase of this project will be the building and operation of the prototype system. This has been tentatively planned for installation at Plum Brook Station, with a satellite system implemented at GRC.

Dr. Kocher has also been investigating the development of a garnet abrasive recycling system (with a graduate student – Amarim Kongtawelert). Bench-scale units have been designed, built and tested. The final design and construction of the prototype unit is currently underway. This unit will be installed for use at the Fabrication Shop at GRC.

These projects are being considered for further funding by NASA GRC. It is anticipated that each of these projects will be continued, to varying degrees, at least through the Fall Semester of 2002.

Name: **Javier A. Kypuros**
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Colleague: 5530/Kevin J. Melcher

Assignment:

Active Control of Turbine Tip Clearance

Recent studies by U.S. engine manufacturers have shown that significant gains in engine life and performance may be obtained by reducing tip clearance, the radial distance between the blade tips and the casing/shroud, in rotating turbomachinery. Ideally, a small nominal clearance would be maintained throughout the flight trajectory. However, this is not currently possible due to a number of mitigating factors: severe environment, weight considerations, and large changes in thermal/mechanical properties. The result is an engine that runs less efficiently and requires more maintenance than one with a small nominal clearance.

The Controls & Dynamics Technology Branch at NASA Glenn Research Center is investigating active control technologies to address the tip clearance problem. These technologies include control methods, system modeling, and actuation technologies. The goal of this research is to eliminate a clearance "pinch point" that results from the turbine rotor/blades and the case having different growth rates.

As currently envisioned, the faculty applicant assigned to this task would conduct a literature search to assess the state-of-the-art in turbine tip clearance control, identify and model (simplified) pertinent transient phenomena impacting the tip clearance, and evaluate the potential of various control approaches to effectively managing tip clearance throughout the flight trajectory.

Research Summary Submitted by Fellow:

A Reduced Model for Prediction of Thermal and Rotational Effects on Turbine Tip Clearance

Turbine blade tip clearance continues to be a concern in the design and control of gas turbines. Ever increasing demand for improved efficiency and increased operating temperatures requires ever more stringent tolerances on turbine tip clearance. A successfully implemented active tip clearance control could potentially lead to improved efficiency, reduced specific fuel consumption, and increased service life.

The focus of this study is to develop a simplified model from first principles that grossly captures the change in dynamic turbine tip clearance during a take-off transient. Such a model can aid in identifying and understanding the primary mechanisms involved in the turbine tip clearance problem and their inherent frequency response. This work serves to identify knowledge gaps that must be addressed in order to facilitate design and development of an actuator and control strategy for active clearance control and perhaps to synthesize a higher fidelity model suitable for *virtually prototyping*[1] the control/actuation mechanism. The purpose of beginning with this reduced approach is to eliminate the necessity for a finite-element model that would require detailed information about geometry specific to the particular application. The model developed is intended to be more generic.

The main objectives of this study can be summarized as follows:

1. Identify and characterize the primary mechanisms involved in turbine tip clearance;
2. Identify the known and unknown parameters necessary to predict turbine tip clearance (or summarize the state of knowledge); and
3. Develop a simplified model that can later be used to
   (a) reasonably represent turbine tip clearance during common gas
   (b) turbine transients (take-off, reburst, etc.),
   (c) predict necessary actuator performance requirements, and
   (d) serve as a baseline for virtual prototyping of control/actuation system.

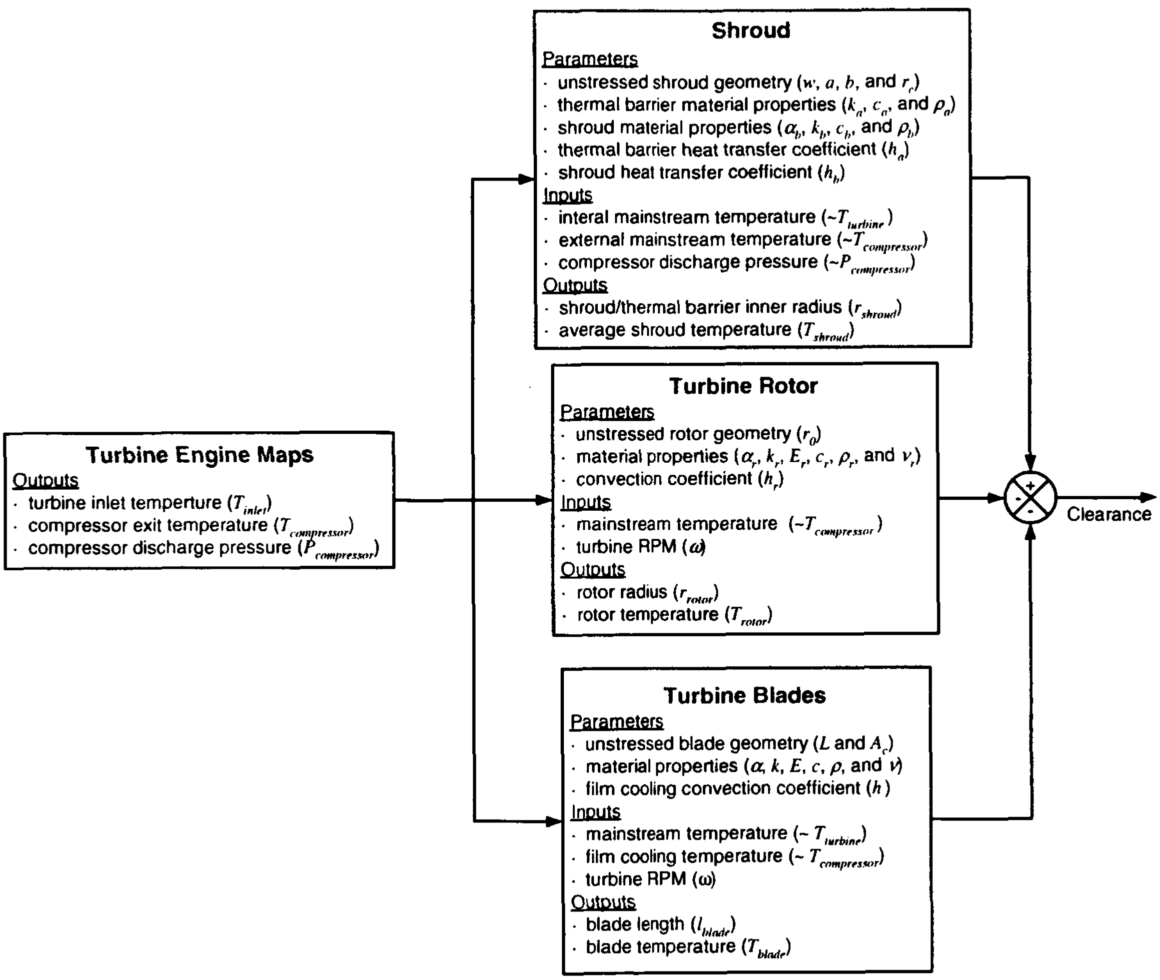
Previous NASA efforts in collaboration with industry have quantified tip clearance transients using both experimental and numerical results [1, 2, 3]. Due to proprietary issues, these reports, however, do not describe analysis used to derive numerical results. Much of this work has been reserved for classified reports using proprietary finite-element tools, and few publications document the combined effects of both thermal and mechanical stresses experienced by the rotor, blade, and shroud. Little has been published on the stress analysis used to predict deflections of the rotor, blade, or shroud. Most of the finite-element studies in the area focus on long term effects like creep and crack propagation and do not focus on prediction of deflections due to thermal and rotational transients during flight. Significant experimental and numerical work has been published on the film cooling of turbine blades [4, 5, 6, 7, 7]. For NASA to conduct fundamental research that will facilitate future technologies in active turbine tip clearance control, a valid model or a test rig is necessary. The test rig can be potentially costly, especially if not thoroughly planned. A model-based simulation is less costly, is useful in designing the test rig and associated experiments, and (if sufficiently accurate) can be used to virtually prototype the controller/actuator mechanism.

As shown in Figure 1, the proposed model incorporates three basic elements – the shroud, rotor, and turbine blade. In order to predict deflections of each element due to thermal and mechanical stresses the temperature, pressure, and force distributions in each element must be modeled. The block diagram shows the parameters necessary

[1] *Virtual prototyping* refers to the process by which models and simulations are employed to *virtually* design and test mechanisms and/or controls.

to calculate the temperature and stress distributions. An engine model is employed to provide the speed, temperature, and pressure transients to the shroud, rotor, and blade sub-models. Each sub-model predicts deflections due to thermal and mechanical stresses. The time-varying geometry is then outputted to calculate the overall change in clearance.

The analysis is organized by the three system elements – the shroud, rotor, and blade – previously discussed. Each element is presented by describing parameters and boundary conditions necessary for analysis and detailing assumptions used to facilitate results. Analysis used to determine thermal and mechanical deflections is described for each element. Then preliminary results of clearance prediction are presented and discussed. The knowledge gaps of most concern are identified and summarized.



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Name: **Choon S. Lee**
Education: Ph.D., Electrical Engineering
University of Illinois

Permanent Position: Associate Professor, Electrical Engineering
Southern Methodist University

Host Organization: Communications Technology Division
Colleague: 5640/Felix A. Miranda

Assignment:

Development of Low-Cost Electrically Beam-Steering/Direction-Finding Antennas

The goal of this research is for the development of low-cost electrically beam-steering/direction-finding antenna arrays. The state-of-the-art MMIC based phased array, which uses solid-state phase shifters to achieve beam steering, has two serious drawbacks: high cost and complex integration involving multi-layer structures and high-density vertical interconnects. The assignment for the summer is to investigate alternative low-cost phase shifting scheme for beam steering, and to implement this new scheme on a small array. The work will involve design, fabrication and characterization of a small prototype array, and demonstration of the array's beam steering capability.

Research Summary Submitted by Fellow:

Dynamically Reconfigurable Artificial Impedance Surface Approach for Space-fed Steerable Arrays

The goal of this research is to develop a highly efficient (comparable to reflector antennas) electronically steerable **D**ynamically **R**econfigurable **I**mpedance **S**urface **A**ntenna (DRISA). The MMIC based phased array, which uses solid-state phase shifters to achieve beam steering, has two serious drawbacks: high cost and complex integration involving multi-layer structures. Here a novel steering array antenna will be investigated. The proposed antenna is efficient and low in cost compared to existing phased array antennas. The potential low cost arises from the fact that DRISA does not require expensive phase shifters and it can be small in size due to its high efficiency.

The proposed antenna is similar to a single-reflector antenna except that the reflector is replaced by a reconfigurable flat surface. In this novel antenna the phase change of the reflected wave at the aperture plane required for a focused beam is achieved by varying the surface impedance. There are two phases of the project. During the first phase, the surface impedance is changed by a simple mechanical means. The second phase is for developing an electronic means (e.g., micro-electromechanical systems (MEMS) actuators) to change the surface characteristics, thus achieving an electronic beam steering.

During my tenure for summer 2002, I worked toward completing the first phase for the proof of concept. The theoretical formulation is based on physical optics. The theoretical results indicate that the proposed antenna system with an altered surface impedance gives the antenna characteristics that are very similar to those of a comparable conventional single-reflector antenna, within experimental errors.

Currently, the fabrication of the proposed antenna is close to completion but not ready for testing. Antenna characterization will be followed right after the antenna fabrication is complete.

It is proposed that the second phase will be carried out at the home institution of the principal investigator (i.e., SMU) in collaboration with NASA personnel through a mutual agreement yet to be determined.

Name: **Arkady I. Leonov**
Education: Doctor of Science
Karpov's Physics – Chemical Research Institute (Russia)

Permanent Position: Professor, Polymer Engineering
The University of Akron

Host Organization: Materials Division
Colleague: 5150/Alan D. Freed

Assignment:

A Thermodynamic Theory of Solid Viscoelasticity

Finish constitutive development for a non-linear viscoelastic solid and write it up for submission to a journal for publication.

Research Summary Submitted by Fellow:

Three types of research activities I developed when participated in the Summer Program.

1. Along with Dr. Freed, I participated in developing a general, thermodynamically related theory of nonlinear, non-isothermal, compressible viscoelasticity. The general theory has been completely formulated and sent for publication to **J. Mech. Phys. Solids** as three papers in the series:

   (i) A.D. Freed and A.I. Leonov, *A Thermodynamic Theory of Solid Viscoelasticity. Part I: Linear Viscoelasticity.*
   (ii) A.D. Freed and A.I. Leonov, *A Thermodynamic Theory of Solid Viscoelasticity. Part II: Nonlinear Thermo-Viscoelasticity.*
   (iii) A.D. Freed and A.I. Leonov, *A Thermodynamic Theory of Solid Viscoelasticity. Part III: Nonlinear Glassy Viscoelasticity, Stability Constraints, Specifications.*

This type of theory, mostly applicable to behavior of cross-linked rubbers, creates a scientific foundation for predictions of sealant behavior in airplanes and spaceships under severe, vibration conditions. We have already planned the series of experiments to develop, and related problems to solve, to accumulate a preliminary knowledge necessary for making recommendations.

2. Dr. Freed and I started a new project, which can be related to the problem of creating artificial muscles. This is a fast growing theory of nematic elastomers. In spite of many recent publications and efforts, the theory has not been much developed in this area. This project will be continued.

3. I also participated in research seminars led by Dr. M. Meador, which mostly discussed chemical features of new thermoset resins, sometimes also discussed a

complicated physico-chemical and flow behavior of polymer-clay nano-composites. Because I was interested and involved in research of physics and rheology of polymer-clay nanocomposites, Dr. Meador suggested presenting my overview of these materials on his seminar. Therefore on July 17, I made on the seminar a conceptual report, “Remarks on Physico-Chemistry of Polymer-Clay Nanocomposites”.

Some of these research problems have been discussed for a possibility to get a support from NASA.

Name: **Paul P. Lin**
Education: Ph.D., Mechanical Engineering
University of Rhode Island

Permanent Position: Professor, Mechanical Engineering
Cleveland State University

Host Organization: Microgravity Science Division
Colleague: 6727/Kenol Jules

Assignment:

Multi-sensor Acceleration Data Processing Coupled with Sensor Data Fusion for the ISS Microgravity Environment Monitoring System

The artificial intelligence monitoring program, which was developed to monitor the microgravity environment onboard the International Space Station (ISS) over the last two years, will be modified over this 10-week period by incorporating the following four tasks:

1. The current program is setup to receive, process, analyze, identify and classify events or patterns, based on acceleration data measured in near real time, onboard the ISS from only one accelerometer at a time. The work over this summer will extend such capability of the monitoring system to N-accelerometers at any time. The system shall be able to receive, process, analyze, identify and classify acceleration data from any number of accelerometers specified by a user.

2. A semi-automated process shall be developed to ease the tedious analysis process involved with the off-line "unknown database", which is used to assess which events or patterns detected from the real time mode of the monitoring system are real events or white noise effect or transient phenomena. The product of that task shall be a somewhat automated process which allows the analyst to process "in bulk" acceleration data (over many days of data collection) within a few hours.

3. Another area, in which work shall be performed over this 10-week summer tenure, is data fusion. Since task 1 calls for multiple accelerometers data processing, this shall lead to multi-sensor fusion integration and data interpretation. This task shall focus on multi-sensor data fusion. The product of this task shall be a multi-sensor data fusion, which implements the concept of data fusion as part of the program (in Matlab).

4. At the end of the 10-week tenure, the artificial intelligence monitoring system user manual shall be updated to reflect all the changes that were added to the program during the summer tenure.

Research Summary Submitted by Fellow:

Multi-Sensor Data Processing, Fusion and Interpretation for the ISS Microgravity Environment Monitoring System

The existing system-monitoring program was designed to process and analyze the acceleration data from one sensor at a time. Therefore, the task for this project is toextend the monitoring capability to multiple sensors at the same time. The specific tasks for this project are briefly described as follows:

Data Processing

The modified computer program is designed to automatically retrieve the system's input files from a specific sensor. In addition, the system's output files are generated and automatically saved under the sensor specific path.

To avoid data cross talking, a Window is opened for each sensor. In each Window a computer program is executed.

Data Analysis

The computer program classifies the detected patterns into known and unknown patterns. At first, most patterns are unknown which requires a great deal of time for analysis. In this regard, a semi-automated process was developed to ease the tedious data analysis.

The process begins with the detected peaks in PSD data, which have been collected for several days. The data contains the detected frequencies, their corresponding calculated accelerations, and other information such as date of data receiving and Sensor ID. All frequencies with an increment of frequency resolution are analyzed to determine the number of occurrence (i. e. histogram), and their respective percentiles. The range of RMS acceleration for each frequency during the recorded period of time is also automatically recorded. The key factors in determining if a detected frequency and acceleration constitute a known pattern are the two percentiles. The first percentile has to do with the degree of repeatability of a frequency with respect to others, while the second one has to do with the degree of acceleration variation with respect to others. The scattered plot of frequency versus RMS acceleration is no longer needed. However, it can be used to visualize how patterns scatter. As a result of this process automation, approximately 75% of analysis time is saved.

Sensor Fusion and Interpretation

As mentioned earlier, one program is executed for each sensor. In addition, one level above each program, there is a system-monitoring program that constantly monitors the active sensors. This program also allows the user to change the program's configurations at any time.

Each program performs many tasks such as source detection, pattern classification, pattern recognition and confidence determination, and produces five different kinds of outputs. They are all in Excel spreadsheets as follows:

(1) Known patterns
(2) Unknown patterns
(3) Data arrays for web display
(4) External log files
(5) Internal log files

The data arrays and log files are automatically saved into the sensor specific database. It is worth of noting that except the data in known and unknown patterns, the degree of confidence (DOC) between 0 and 1 for each identified vibrating source is calculated. The DOC is based on the degrees of belongingness in frequency and acceleration, respectively, and the degree of sensor relevance to the detected source. In the case of the same source, but detected at different frequencies, the frequency that has the highest DOC is chosen to interpret the sensor data. In the case of the same source detected by multiple sensors, logically the sensor that is most relevant to the detected source should be chosen to interpret the sensor data. However, the multi-sensor fusion also has to do with the location of the space experiment (which might be affected by the source's vibration), and its relationship with respect to the sensor, and with respect to the source. Due to the complexity of such a sensor fusion scheme, the locations of experiments were not considered in this project.

Conclusions

The data analysis process has been greatly improved from manual to semi-automated. The developed sophisticated computer program is now capable of processing and analyzing multiple sensors at the same time. Automatic output database generation for each specific sensor has also been accomplished. Future work may include enhancement of multi-sensor data fusion, which indeed, is a very complex and challenging task.

Name: **Jerzy Sawicki**
Education: Ph.D., Mechanical Engineering
Case Western Reserve University

Permanent Position: Professor, Mechanical Engineering
Cleveland State University

Host Organization: Structures and Acoustics Division
Colleague: 5920/George Y. Baaklini

Assignment:

Modeling of the TF41-Fan Disk Crack Detection Seeded Fault Test

TASK I. Establish with Researchers at GRC full experimental simulation of the overhang fan disk on the Disk Spin Simulation System at GRC limited only to the capability of the spin system. Task should include:

- Employment of a variety of sensors, i.e., capacitive DC displacement sensors, Eddy current displacement probes, and accelerometers
- Rigid and flexible shaft operation
- Implementation of high-speed data acquisition system
- Optimal sensor placement will be determined based on the sensitivity analysis

TASK II. Develop vibration-based model-dependent method for the crack detection and growth. The modal norms method will utilize finite element analysis techniques together with experimental results, to detect, locate and quantify the damage. With the appropriate structural/rotordynamic modeling the method will be able to provide on-line global and local damage information without human accessibility to the structure/rotating disks.

Task III. Help in the write-up of the safety permit and procedures

Research Summary Submitted by Fellow:

Modeling of TF41 Engine Rotor-Bearing Fan Disk Crack Detection Seeded Fault Test

This report presents partial results of the modeling and dynamic analysis of the Allison TF-41 turbofan engine, which was used by several aircrafts during the 1960s and 1970s. The engine produces about 15,000 pounds of thrust and consists of two coaxial rotors. These two rotors consist of compressor and turbine stages which are connected by flexible shafting. The inner rotor, called the low-pressure rotor (LP rotor) is supported by three rolling-element bearings, each of which is mounted to the case structure. The low pressure-intermediate pressure compressor (see Figure 1, [1]) is driven by a two-stage low-pressure turbine. The outer rotor, called the high-pressure rotor (HP rotor), is supported principally by three rolling-element bearings. There is one intershaft differential rolling-element bearing connecting the LP and HP rotors. The schematic of a two-rotor-bearing system is shown in Figure 2. The two rotors are aerodynamically coupled, and have a bilinear low/high speed relationship.

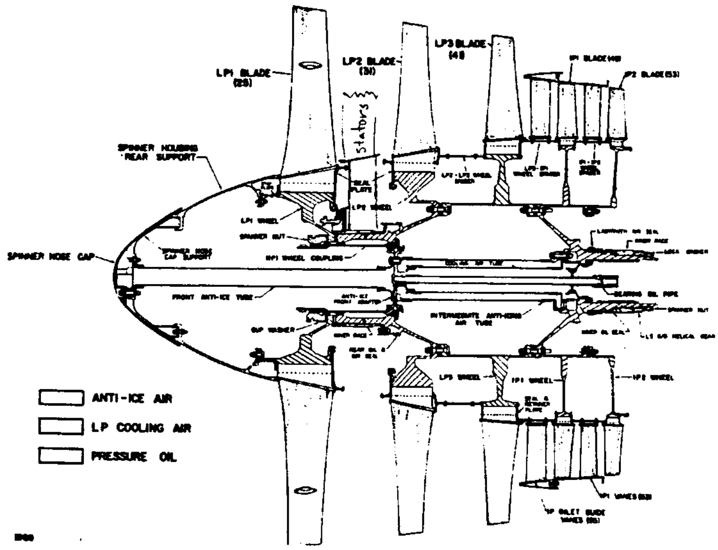


Figure 1. Low pressure-intermediate pressure compressor rotor section view of TF41 engine.

The requirement of high specific power output for gas turbine aircraft engines has resulted in highly flexible rotor designs. These rotors typically operate above several critical speeds. The typical gas turbine engine requires a complex analysis to accurately predict response from rotor unbalance throughout the entire engine power range. The analysis presented herein includes both flexible rotors, the effect of intershaft bearing, and the bearings connecting the rotors to the engine case. The case is considered rigid, although casing flexibility may be an important effect in certain applications. The analysis includes critical speeds and unbalance response. Since the two rotors each have different speeds at a given power setting, a separate critical speed analysis is necessary for the frequency range of each rotor. For the given unbalance condition, the speed of the exciting (unbalanced) rotor is varied over its entire range. The speeds of the excited (balanced) rotor are determined from the provided rotor speed relationships [2,3].

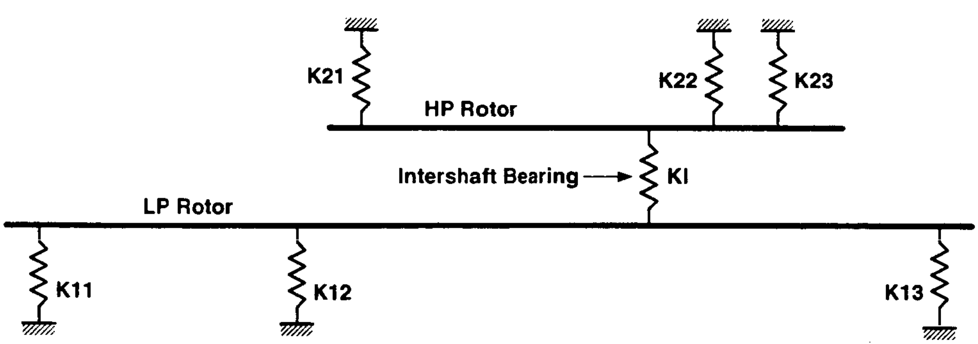
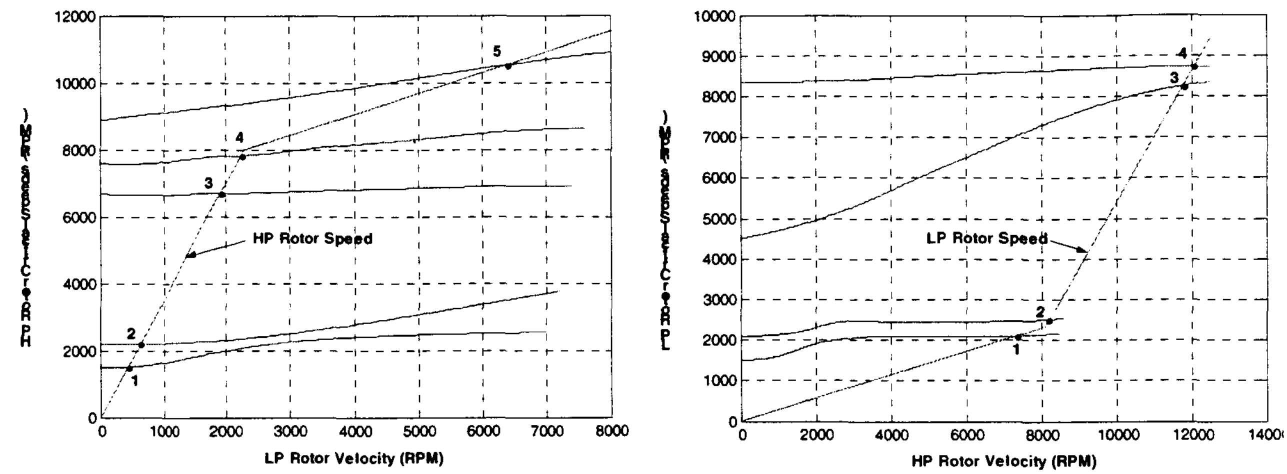


Figure 2. Schematic of computer model of TF41 engine.

Figure 3 shows the HP rotor excited critical speeds (Fig. 3(a)) and the LP rotor excited critical speeds (Fig. 3(b)) for the case when all bearings are rigidly mounted to the support structure. The summary of critical speed values is presented in Table 1. The first two HP-excited critical speeds occur early in the starting transient and the rotors will pass rapidly through these speeds conditions. The next two HP-excited critical speeds occur near idle speed and consist of bending of the LP rotor and pitching of the HP turbine about its spline joint. The fifth HP-excited critical speed is in the operating speed area and consists of the pitching and bouncing of two rotors.



(a) (b)

Figure 3. Engine critical speeds: (a) HP rotor excited critical speeds, (b) LP rotor excited critical speeds.

HP Rotor Critical Speeds (RPM)	**LP Rotor Critical Speeds** (RPM)
(431,1500)	(7319,2100)
(632,2200)	(8211,2504)
(1920,6680)	(11776,8255)
(2246,7818)	(12060,8710)
(6377,10524)	

Table 1. Summary of critical speeds arranged in pairs (ω_1,ω_2), where ω_1 is the speed of LP rotor and ω_2 is the speed of HP rotor.

The first two LP-excited critical speeds occur near engine idle speed and these modes consist of engine pitching and bouncing, and pitching of the HP turbine about its spline joint (in a second mode). The next two LP-excited critical speeds occur in the operating range. The mode shapes corresponding to these critical speeds consist primarily of bending of the LP rotor and some pitching of the LP and HP rotors.

The main goal of this effort was to establish the vibration response characteristics for the full-scale TF-41 engine crack detection seeded fault test conducted in China Lake, CA, on May 7-8, 2002. Figure 4 illustrates the magnitude and phase of vibration response to the unbalance mass added to the 32" fan [4]. The experimental data suggest the existence of critical speed around 5200 rpm, which is different than the one predicted numerically herein (see Table 1). This maybe indicative of bearing mounts with dampers whereas in our computer model, all bearings were assumed rigidly mounted. Future models will be modified for different types of bearing mount based on experimental data like that in Figure 4, in order to capture and differentiate between vibration signatures indicative of crack initiation and growth.

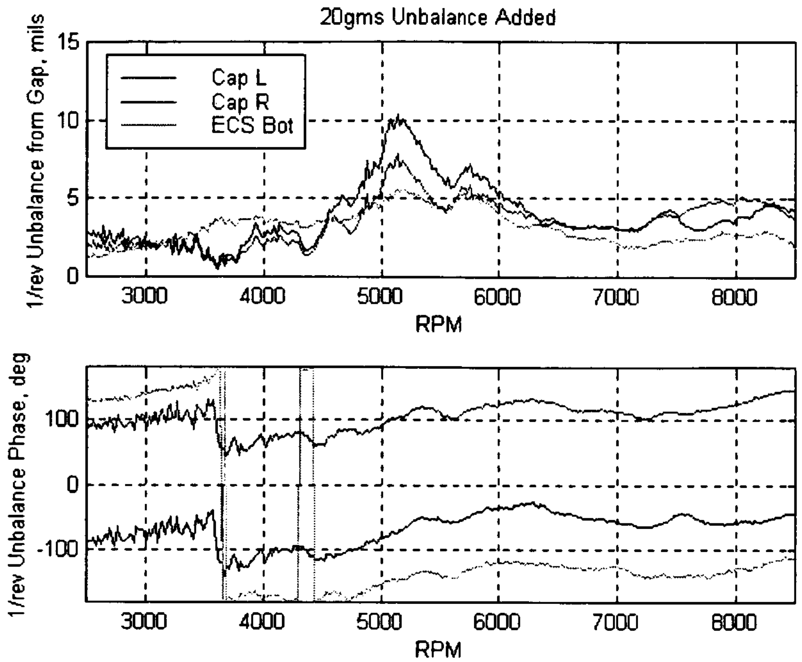


Figure 4. Unbalance magnitude and phase calculated from tip clearance (20gms of unbalance mass added at a 5.6" radius for this run) [4].

[1] Materials from TF41Engine Operational Check & Test Participants Meeting, Naval Air Warfare Center, China Lake, May 23, 2002.

[2] B. Watts, Allison Advanced Development Co., Personal Communication.

[3] P. Onowen, Rolls-Royce, Personal Communication.

[4] P. Tappert and A. von Flotov, Summary of TF-41 Baseline Measurements, China Lake, CA, May 7-8, 2002, Hood Technology Corporation, Hood River, OR.

Name: **Alfred B-O. Soboyejo**
Education: Ph.D., Structural Engineering and Mechanics
Stanford University

Permanent Position: Associate Professor, Aeronautical and Astronautical Engineering
The Ohio State University

Host Organization: Research and Technology Directorate
Colleague: 5000/Christos C. Chamis

Assignment:

The fellow will research the potential application of the Multi-Factor Interaction Model (MFIM), to describe the complex behavior of structural and nonstructural materials subjected to hostile operational conditions. The research will also address the evolution of degradation mechanisms in sustained operating conditions. It will also include the development of "formal proof" of the validity of the results obtained by the model. Time permitting: Another aspect of the research is the potential substructural representation of the MFIM, in order to be more inclusive of lower scale factors that may influence several next higher level scale factors that will render MFIM applicable to bio and agricultural evolutionary descriptions

The fellow will end his summer tenure by documenting his findings in a NASA Glenn Research Center report style and make an oral presentation prior to returning to his institution.

Research Summary Submitted by Fellow:

Multi-factor Interaction Model: A New Model with Wide Applicability in Engineering and Applied Sciences

INTRODUCTION AND BACKGROUND

Dr. Christo C. Chamis, an outstanding and renown world-class engineer and scientist, developed the new multi-factor interaction model (MFIM) which has wide applications in engineering, applied sciences, information technology, engineering-economic planning and public policy. Dr. Jim Guptill, a mathematician, developed the innovative and useful NASA computer program for the practical applications of the MFIM. Both Dr. Christo C. Chamis and Dr. Jim Guptill now carry out advanced engineering research at NASA Glenn Research Center in Cleveland, Ohio, U.S.A. The author of this technical report, Dr. Alfred B. O. Soboyejo won a NASA Faculty Fellowship, for the year 2002, and worked with these two U.S. experts at the Glenn Research Center in Cleveland, Ohio. Dr. Alfred B. O. Soboyejo successfully developed and made use of the multi-parameter interaction model (MPIM), in his PhD thesis in 1965 in structural engineering and applied mechanics at Stanford University, Stanford, California. Between 1965 to the year 2002, Dr. Alfred B. O. Soboyejo had gained considerable experience in several applications of the MPIM in engineering, applied sciences and probabilistic engineering methods.

Engineering practice is an art of making use of natural resources for the good and benefit of mankind. However, it is well known that the development of engineering practices had suffered immensely because of inadequacies of engineering sciences to provide reliable theoretical tools to solve practical engineering problems.

The MFIM is principally developed to fill the vacuum created by the inadequacies of existing theories in engineering sciences; by using the MFIM as reliable and useful tools, for the characterization of any desirable effect or outcome in terms of the independent multiplicative effects of functions of the causes, which can bring about the desirable effect or outcome. The theoretical development of the MFIM is highlighted in this technical report. The validations of the theoretical principles developed are demonstrated to several major areas of engineering and applied sciences. There is absolutely no doubt that the MFIM is an extremely useful tool for the successful implementation of any program of engineering-economic planning, analysis and design of components and systems of machines, structures and infrastructures.

SUMMARY

This technical report highlights the theoretical development of the multi-factor interaction model (MFIM). The wide practical applications of this model in forty-four (44) investigations or studies in the areas of engineering, and applied sciences, including engineering-economic planning and public policy are discussed. The multi-parameter interaction model (MPIM) is also developed as a model, which basically has the same mathematical form as the MFIM. The mathematical relationships between these models are established in this technical report. Forty-four (44) summaries of technical investigations were carried out in order to validate the theoretical development of the MFIM. Another twenty-six (26) important areas of engineering and applied sciences are mentioned in this technical report, where the methodology of the multi-factor modeling methodology can provide useful and reliable practical solutions to several problems. The importance of the MFIM as a tool with versatile applications is discussed. Further research with the applications of the MFIM is strongly recommended.

CONCLUSIONS AND RECOMMENDATIONS

1) There is no doubt that MFIM is indeed a most important top level model with several useful applications, which certainly deserve further detailed studies and research. This development will bring about practical solutions to several problems in engineering and applied sciences, not only to NASA, but also to the US and the whole world.
2) Further detailed research and studies, with the use of the multi-factor modeling approach, are strongly recommended in the following fields of engineering and applied sciences: Materials and Structures, including Advanced Materials and Aerospace Structural and Mechanical Engineering. Biomaterials, Bioengineering,

including Biomechanics of Bone Strength in Space, Food, Agricultural, Biological and Biosystems Engineering, including Advanced Life Support Systems (ALSS) in Space.

3) In order to realize the objectives of the research studies mentioned in (2) above, a five year program of research and development had been planned jointly with NASA for execution.

Name: **Sanq-Sub Sonq**
Education: Ph.D., Polymer Engineering
University of Akron

Permanent Position: Assistant Professor, Mechanical Engineering
North Dakota State University

Host Organization: Materials Division
Colleague: 5150/Sandi G. Campbell

Assignment:

Investigation of the processing of advanced polymeric materials and polymer-clay nanocomposites using resin transfer molding.

Research Summary Submitted by Fellow:

Nanocomposites of Modified PMR-type Polyimides/Layered Silicates

ABSTRACT AND OBJECTIVE

The study is to develop the branched high temperature nanocomposite polyimides by enhancing the melt flow of polymerization of monomeric reactant (PMR) -tpye polyimides with layered silicates so that are employed these nanocomposites to the advanced carbon fiber composites for aerospace and aircraft applications. Previous efforts at NASA-GRC have had successful nanocomposites results, however there has been little time and efforts to develop a low viscosity polyimides nanocomposites such as the cost-effective resin transfer molding process. The understanding of structure, properties and processing relationships on new nanocomposites is important to their proper design and construction of process. This research project aims to achieve the following goals:

1. Development of the nanocomposites of the enhanced viscosity PMR-type polyimides with layered silicates;
2. Structure characterization including Differential Scanning Calorimetry (DSC), Thermal Gravity Analysis (TGA), Dynamic Mechanical Analysis (DMA), Thermal Mechanical Analysis (TMA), X-ray diffraction and rheological properties of nanocomposites;
3. Study of processing parameters depend upon thermal curing processing;
4. Development of advanced high temperature carbon fiber composite materials with the nanocomposite PMR-type polyimides matrix;

I. INTRODUCTION AND BACKGROUND

Polyimides are considered to one of the most important super-engineering polymers because of their superior mechanical properties and thermal stability at high temperature. NASA has developed a polyimide composition referred to as PMR-15, that reacts chemically to form a reinforced polymers that is highly resistant to heat and oxidation. At present, PMR-15 advanced composites materials are used to engine parts application. However, the processing of PMR-15 has been limited to prepreg-based methods, such as compression molding or autoclave processes but the parts manufacturing are not cost effective. There is a need to develop new high temperature polymer composites that will lead to lower cost and improve processability for large structures lightweight composites materials for power and propulsion components. The development of resin transfer molding (RTM) processable high temperature polymers has been the subject of intense research activity [1-3].

Nanocomposites are new class of composites in which the reinforcing phase dimensions are in the order of nanometers. Because their extremely high aspect ratios (surface-to width) due to nanometer size, nanocomposites promise to exhibit novel and significantly improved physical, chemical, and mechanical properties. Polymer-clay nanocomposite are classified two types [4]. The intercalated nanocomposites, which are formed when one or a few molecular layers of polymer are, inserted the clay galleries between the interlayer spacing. Exfoliated nanocomposites are formed when the silicate nanolayers are individually further dispersed in the polymer matrix. In order to develop nanocomposites of the modified low viscosity PMR-polymides/layered silicates with high temperature performance and stability, at least two requirements must be satisfied. One is dispersion into matrix and the other is to control the interfacial affinity between a clay particle surface and matrix polymer.

II. ACCOMPLISHMENT:

The following is accomplished on my research during this summer:

1. Synthesis of Nanocomposite Polymers
   Nanocomposites of modified PMR-polyimides with layered silicates is synthesized depending upon various amounts of silicates and trifunctional amine (TAB). For this preparation, the best optimized formulation of Design of Experiments (DoD =1250) method as suggested by NASA researcher [5] used.

2. Post-Curing process of Nanocomposites Resin
   Molding powders synthesized of nanocomposites containing with/without layered silicates is cured at and 700°F for one hour using compression molding.

4. Lamination Process of Carbon Fiber Composite/Nanocomposite Polyimide Resin
   Carbon fiber reinforced composites will be prepared by lamination process from nanocomposites polyimides using compression molding processing. The T650-35 carbon fabric will be used for reinforced materials.

5. Characterization and Rheological Properties
   a. Thermal Characterization: Nanocomposites is characterized for measuring glass transition temperature of the neat resin (uncured) and cured nanocomposites. The instruments were used dynamic mechanical analysis (DMA) and thermal mechanical analysis (TMA) and TGA.
   b. Differential Scanning Calorimetric (DSC) measurements are performed with a Dupont Instruments 910 DSC with a heating rate of 10°C/minute.
   c. Thermal Gravimetric Analysis (TGA) is performed to measured degradation of Nan composites using a TA Instruments Model 2950 TGA with an air and nitrogen purge and a heating rate of 10°C/minute.
   d. X-ray diffraction: The 2θ scanning is performed to study the characterized dispersion of nana particles into matrix.
   e. Rheological Properties: Dynamic mechanical analysis is performed on a Rheometric Mechanical Spectrometer (RMS) 800 instrument in the parallel plate mode. The plates were 25.0 mm in diameter. A powder pellet was pressed at room temperature under 325 Mpa pressure. The resulting disks were placed in the apparatus, and the experiment was carried out after the top plate was lowered.

5. Mechanical properties: Mechanical properties including tensile, modulus and flexural properties will be tested in the future.

III. FUTURE WORK

The following research work will be carried out in the future.

1. More synthesis of a series samples to prepare the post-cured samples, measurement of mechanical properties, and characterization of nanocomposites
2. Optimization of processing conditions depending upon processing Parameters
3. Fabrication process of advanced carbon fiber reinforced composites Fundamental understanding of structure, property and processing relationships in nanocomposites

INNOVATION AND POTENTIAL IMPACT

The branched of high temperature polyimides nanocomposites have been little studied. Especially, the low viscosity modified PMR-type polyimide nanocomposites with carbon fiber composites have never been studied.
The new advanced nanocomposites are low viscosity and can be readily applied to a carbon fiber matrix such as low cost resin transfer molding manufacturing techniques. If this development is successful, new advanced composite polymers will be reduced structures weight and cost significantly and improved in properties and performance. For example, the cost-effective fabrication process, such as resin transfer molding will be expected to reduce the components fabrication costs by as much as 50% over traditional prepreg-based methods.

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5. Gariepy, C.A.; Meador, M.A.; Meador, M.A.B.; Eby, R.K. Polym. Prepr., 41,369-370 (2000)

Name: **Dawn E. Spencer**

Education: M.S., Computer and Information Science
The Ohio State University

Permanent Position: Visiting Assistant Professor, Computer Information Systems
University of Southern Colorado

Host Organization: Power and On-Board Propulsion Technology Division

Colleague: 5410/Ricaurte Chock

Assignment:

Integrated Power Systems Modeling

Ms. Spencer will work with our Division's computer systems expert and lead modeler for space missions, a mission analyst, and a university summer student on integrated power systems modeling. This will require expertise in computer systems, artificial intelligence, and databases.

This team will try to describe the steps/ways the GRC System Analysis Team analyzes a Solar Electric Propulsion (SEP) mission. Once these are established, Sight software will be used to attempt to integrate and automate a trade study for a SEP mission.

Also, if Ms. Spencer has the interest and time, her experience would be helpful in updating/redesigning the Division's website.

Research Summary Submitted by Fellow:

Main Project:
Evaluate the iSight application to determine ability to permit Engineers to integrate in-house software applications mainly in the 5410 Branch.

Possible Benefits:
Improved accuracy of simulations due to lessoned reliance on estimations. Engineers could pull their data directly from other engineers work. Ease of optimization.

Results:
iSight did not live up to expectations, proving to be too difficult for an Engineer to use without extensive time and training. One person in the branch would have to be designated the iSight specialist. Another software product, CO, was also looked at, although the demo version could not save so there are no sample applications.

Deliverables:

- Summary of iSight conclusions document including workarounds to some problems.
- Sample application with branch software products ADAM and Savant integrated.

- Production application integrating Tim Sarver-Verhey's Excel application and Savant.
- Short comparison of iSight and CO

Secondary project:
Renovate the 5400 division and 5410 Branch websites as time is available from main project.

Possible Benefits:
Reach Section 508 compliance. Fix errors, broken links, complete name change of Lewis to Glenn, provide a simple standard interface to visitors, speed page loads, ...

Results:
The 5400 Division, and the 5410, 5420, 5430, 5450, 5480, and 5490 Branch websites were renovated. Section 508 Compliance was achieved. Also, the styles of the websites were improved and are consistent with only two designs throughout the division. Many other improvements as listed under 'Benefits'.

Deliverables:
- 5400 Division website (http://powerweb.grc.nasa.gov/)
- 5410 Branch website (http://powerweb.grc.nasa.gov/pvsee/)
- 5420 Branch website (http://www.grc.nasa.gov/www/Electrochemistry/)
- 5430 Branch website (http://www.grc.nasa.gov/WWW/onboard/)
- 5450 Branch website (http://powerweb.grc.nasa.gov/elecsys/)
- 5480 Branch website (http://www.grc.nasa.gov/WWW/epbranch/)
- 5490 Branch website (http://www.grc.nasa.gov/www/tmsb/)
- Document "Keeping Your Site Consistent and Section 508 Compliant" supplied to webmasters
- Short summary report of each renovated site

Status of sites as of 8/8/2002:

	Done	Turned over	Uploaded to server*
Division	x	x	x
5410	x	x	x
5420	x	x	x
5430	x	x	**
5450	x	x	x
5480	x	x	x
5490	x	x	x

*Until the site is uploaded by the webmasters, my work will not appear.
If your browser is caching the old version of a page, hold down shift while you click Refresh (or Reload) to see the new page.

**Webmaster (Marie DiNovo) is waiting to have an account set up for the web server so she can load the site pages.

Name: **Loren B. Sumner**
Education: Ph.D., Mechanical Engineering
Georgia Institute of Technology

Permanent Position: Assistant Professor, Mechanical Engineering
Mercer University

Host Organization: Microgravity Science Division
Colleague: 6712/Bhim S. Singh

Assignment:

An asymptotic analysis is suggested of 2-D flow of a drop supported on the side of a slender channel but separated from the opposite side by a lubricating layer of gas entrained by a thermocapillary driven flow in the drop itself. Experimental efforts at Georgia Tech. began a few years ago by Nalevanko. An analysis similar to that of Sen and Davis but which includes both phases would serve as a viable summer project and would be a considerable contribution to the study of non-coalescence providing new information regarding the physical influences on the shape of the drop interface. This project promises to be productive over a concentrated 10-week effort and could certainly contribute to the Divisions' technical seminar series.

Research Summary Submitted by Fellow:

Thin-film Analysis of the Return Flow and Resulting Interface Shape of a Thermocapillary-driven Nonwetting Droplet

A liquid droplet coating a flat, solid surface maintains separation from an opposing solid boundary with thermocapillary-driven nonwetting. Shear stress at the droplet interface draws the surrounding gas between the droplet and solid boundary producing a lubricating gas layer. The necessary return flow of the gas forces a redirection at the centerline of the droplet resulting in a "dimpled" droplet shape as show below. Experimental studies of nonwetting and noncoalescence have found that interface shape is greatly influenced by this return gas flow[i,ii], yet a theoretical analysis is yet to predict the shape.[iii]

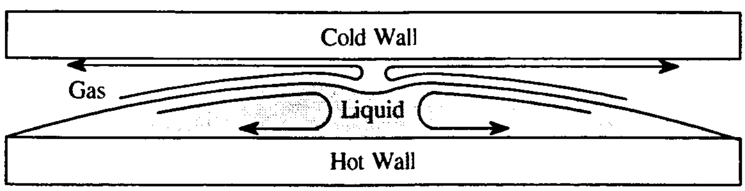


Figure 1. Nonwetting droplet configuration

Dr. Sumner performed an asymptotic analysis similar to that of Sen and Davis[iv] and Sen[v] considering the two-dimensional, coupled liquid/gas flow field of nonwetting in an attempt to determine the droplet shape and identify the influential physics. This effort includes: 1) deriving the appropriate mathematical representation, 2) determining suitable orders of the controllable parameters, Reynolds and capillary numbers,

3) identifying any necessary boundary layers, 4) establishing and solving the leading- and first-order core-flow problem.

In the asymptotic analysis, an aspect ratio, the distance between the solid boundaries divided by half of the droplet length, serves as the perturbation parameter. A two-dimensional core flow is found in the droplet and gas layer with a transition boundary layer existing only in the gas flow near the outer edges of the droplet. Choices of the asymptotic analysis and resulting first-order flow fields and interface shapes suggest that inertia is necessary to attain the "dimple" shape. A sample of the determined droplet shapes to first-order is shown below.

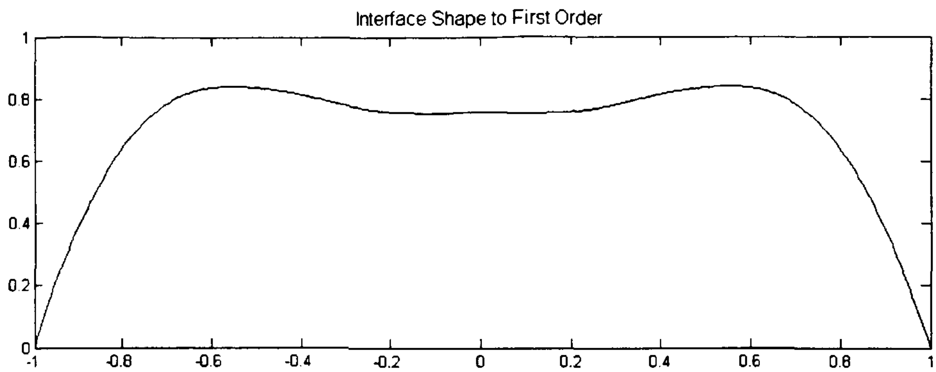


Figure 2. Sample first-order droplet shape

1. [i]P. Dell' Aversana and G. P. Neitzel, 1998 When liquids stay dry. *Physics Today* **51**, 38-41.
2. [1] J. Nalevanko 1997 Design of an apparatus for investigation of 2-D liquid drop non-coalescence. M.S. Thesis, Georgia Institute of Technology.
3. [1] A. M. Wood 2000 Steady thermocapillary flow between a non-wetting liquid droplet and a solid surface. M.S. Thesis, Gerogia Institute of Technology.
4. [1] A. K. Sen and S. H. Davis 1982 Steady thermocapillary flows in two-dimensional slots, *J. Fluid Mechanics* **121**, 163-186.
5. [1] A. K. Sen 1986 Thermocapillary convection in a rectangular cavity with a deformable interface, *Phys. Fluids* **29** (11), 3881-3883.

[i] P. Dell' Aversana and G. P. Neitzel, 1998 When liquids stay dry. *Physics Today* **51**, 38-41.

[ii] J. Nalevanko 1997 Design of an apparatus for investigation of 2-D liquid drop non-coalescence. M.S. Thesis, Georgia Institute of Technology.

[iii] A. M. Wood 2000 Steady thermocapillary flow between a non-wetting liquid droplet and a solid surface. M.S. Thesis, Gerogia Institute of Technology.

[iv] A. K. Sen and S. H. Davis 1982 Steady thermocapillary flows in two-dimensional slots, *J. Fluid Mechanics* **121**, 163-186.

[v] A. K. Sen 1986 Thermocapillary convection in a rectangular cavity with a deformable interface, *Phys. Fluids* **29** (11), 3881-3883.

Name: **Stephen F. Tytko**
Education: Ph.D., Chemistry
Northwestern University

Permanent Position: Assistant Professor, Chemistry
Baldwin-Wallace College

Host Organization: Materials Division
Colleague: 5150/Chun-Hua (Kathy) Chuang

Assignment:

Polymers for Fuel Cell and High Temperature Applications

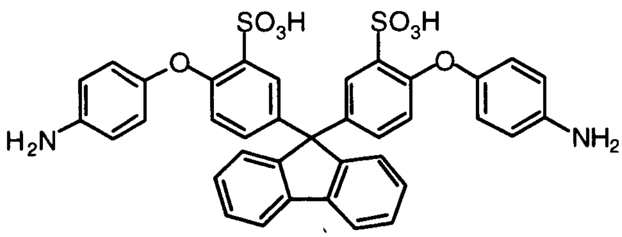
Polyquinoxalines is a class of high temperature polymers that exhibits good solvent resistance, high char yields and excellent thermo-oxidative stability. The challenge of using the polyquinoxaline is its poor solubility in common organic solvents and the difficulty in processability. For this research, effort will be concentrated in synthesizing monomers that would yield soluble polyquinoxalines as high temperature polymers. Additional investigation will focus on attaching the sulfonate groups ($-SO_3H$) to the monomer units to produce sulfonated polymers for potential fuel cell applications. Polymers will be characterized by thermal analysis such as TGA, DSC and TMA. The ionic conductivity and fuel cell activity of the sulfonated polymers will also be evaluated.

Research Summary Submitted by Fellow:

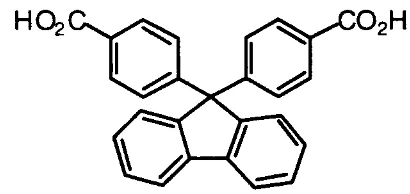
The goal of our research was to prepare polymer exchange membranes (PEM's) for fuel cell applications. The current polymers available for use in fuel cells suffer from limitations such as high cost and a limited temperature range over which they may operate. We wished to attempt preparation of PEM's capable of operating at temperatures in excess of 80°C, the current limits for fuel cells. The target of our research was to prepare sulfonated polymers, capable of operating at elevated temperatures.

Preparation of the monomers centered on several target molecules (Figure 1).

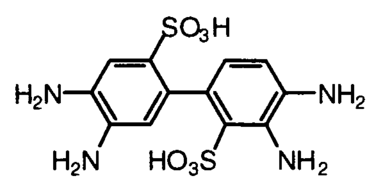
Figure 1



1

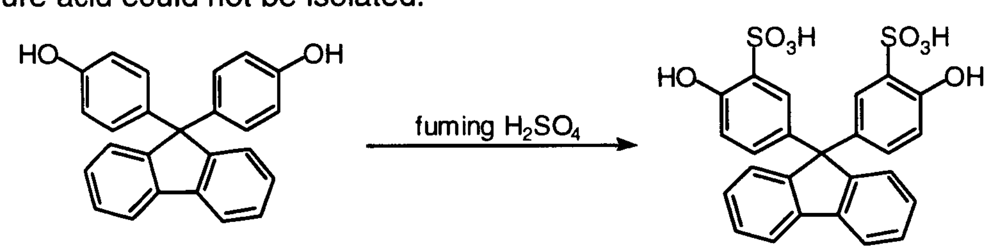


2



3

The preparation of **1** was begun by reacting 9-fluorenylidene-(4,4'-diphenol) with fuming sulfuric acid to produce the disulfonic acid, **4** (Scheme 1). The typical workup procedure for sulfonation procedures consists of neutralizing the reaction mixture in saturated aqueous NaCl. Unfortunately, the disulfonic acid, **4**, is water soluble and it proved impossible to separate the product from the salt. Attempts to add the reaction mixture to absolute ethanol also resulted in failure, as **4** would not precipitate from solution. All attempts to crystallize the acid resulted in the co-precipitation of salt and the pure acid could not be isolated.

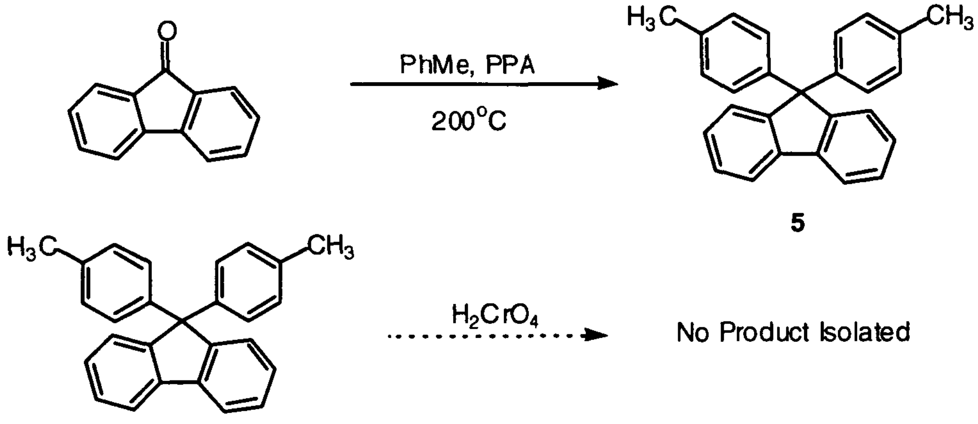


4

Scheme 1

However, addition of the reaction mixture to water, followed by neutralization with calcium hydroxide and careful reacidification allowed the acid to be isolated along with a small amount of calcium salts. No further attempts were made to complete the synthesis of monomer **1** were made, due to a lack of time.

The preparation of 9,9-bis(4,4'-carboxyphenyl)fluorene, **2**, was attempted by reacting 9-fluorenone with toluene in polyphosphoric acid (PPA) at 200°C (Scheme 2). The reaction proceeded slowly, with several byproducts and in poor yield. Efforts to effect

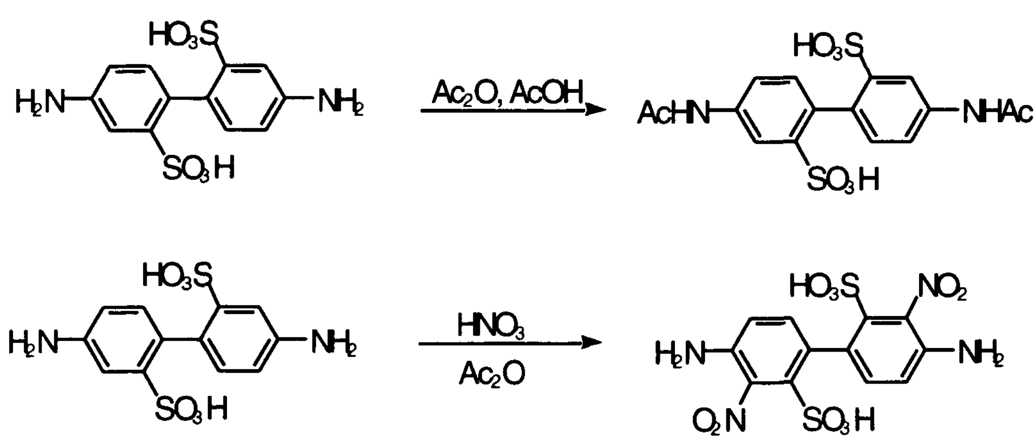


Scheme 2

the reaction using 9-fluorenone in refluxing toluene with sulfuric acid as a catalyst resulted in incomplete conversion of 9-fluorenone after four days at reflux. 9,9-bis(*p*-tolyl)fluorene, **5**, was isolated by crystallization from hexane.

Attempts at oxidizing the methyl groups of **5** met with failure. Jones' reagent failed to give any oxidized product, possibly due to destruction of the ring system. Oxidation with sodium dichromate in refluxing acetone/water failed to give any reaction after four days by TLC.

Preparation of 3,3'-diamino-2,2'-benzidinesulfonic acid, **3**, was attempted by first acetylating 2,2'-benzidinesulfonic acid (Scheme 3). Due to the insolubility of the starting material, no product could be isolated. Infra red analysis of the product of direct nitration



Scheme 3

of 2,2'-benzidenesulfonic acid showed no nitro group present. This aspect of the project was then discontinued.

Efforts to complete the syntheses of these compounds will be continued.

Name: **Hornsen Tzou**
Education: Ph.D., Mechanical Engineering
Purdue University

Permanent Position: Professor, Mechanical Engineering
University of Kentucky

Host Organization: Structures and Acoustics Division
Colleague: 5930/Ho-Jun Lee

Assignment:

Non-Linear Smart Structures Model Development

Professor Tzou will work towards the development of non-linear finite element models and control algorithms for smart structures. The analytical models will complement existing in-house macro-scale and micro-scale models, as well as experimental work being performed cooperatively. Numerical studies will be conducted to demonstrate the utility of the non-linear models for active control and passive damping using piezoelectric materials and shape memory alloys. This research will help advance ongoing efforts to develop morphing structures for applications in aeropropulsion components being performed under the Revolutionary Aeropropulsion Concepts Project (RAC) of the R&T Base Propulsion and Power Program.

Research Summary Submitted by Fellow:

NASA-Glenn is well recognized for its cutting-edge R&D in aero-propulsion systems. Before my visiting Glenn, I have to admit that I know little about turbine engines, although I have about 300 publications on smart structures and structronic systems, micro-sensing/control and opto-piezo-thermoelasticity, aircraft and space structures, etc. Interactions with a number of distinguished NASA scientists made me a better researcher understanding the issues of modern turbine engines. Here is a brief summary of my major accomplishments for my ten-week tenure at Glenn. Because of propriety information, I have to apologize that I can only briefly describe my activities. You may contact appropriate scientists for detailed information.

MAJOR ACCOMPLISHMENTS

- Worked on turbine engine clearance control and proposed new designs based on the structronics technology. Dr. H.-J. Lee and Dr. Steve Arnold are evaluating the designs and possibly submit to NASA Technical Disclosure. (Consult with Arnold and Lee for propriety info.)
- Worked with Dr. Lee and Dr. Arnold and developed research proposals on turbine engine clearance control submitted to R.A.C.
- Worked with Dr. James Min and Prof. T.S. Reddy (advised by Dr. George Stefko) on a proposal focusing on aeroelasticity based smart turbomachinery design also submitted to R.A.C. (Consult with Min and Reddy for further info.)
- Delivered one seminar at the Branch and one at the University of Akron.

- Co-authored two papers with Dr. Lee.
- Worked with Dr. Arnold on medical devices. New designs based on hybrid actuators are proposed. (Consult with Arnold for propriety info.)
- Reconnected with my long-lost, about 20 years, graduate-school friends. Also, enjoyed the impressive collections at the Cleveland Art Museum.

Name: **Brian L. Vlcek**

Education: Ph.D., Mechanical Engineering
Rensselaer Polytechnic Institute

Permanent Position: Assistant Professor, Mechanical Engineering Technology
Georgia Southern University

Host Organization: Research and Technology Directorate

Colleague: 5000/Robert C. Hendricks

Assignment:

1. Develop data analysis methodologies based on Weibull Statistics to determine lifing trends in turbine disks and other components of rotating machinery. This work is in support of our effort to assess and evaluate fatigue data and component lifing in rotating systems.

2. Develop disk and rotating machinery models using CAD/ProE/Unig or related codes to define geometries for FEM-analysis and lifing models. Also work with 3-D scanners to determine profile geometries and credibility of design/fabricated models. This work supports modeling and analysis of field hardware removed for cause to determine residual component life.

3. Develop element and component fatigue testing procedures, analysis of data and implementation into design FEM and lifing codes. This work supports an ongoing effort to provide probabilistic design codes with statistically significant strength of materials data sets.

Research Summary Submitted by Fellow:

Life Prediction of Components and Systems

The main theme of this second summer of research activities at NASA Glenn Research Center was the refinement, validation, and application of probabilistic lifing techniques. I worked with Robert C. Hendricks.

Probabilistic approaches recognize the fact that material strength varies from sample to sample as a result of material inhomogeneities and manufacturing variability. The applied loads to a system are also variable as a result of operation or mission cycle (start-up, cruise, wind down) and environmental factors. As a result, component life must be modeled as a statistical variable. If the applied load is known in terms of duty cycle and relevant correction factors, the component's probability of failure is determined assuming that the component's life is represented by a known probability function. W. Weibull was the first to suggest a reasonable way to estimate component life. Lundberg and

Palmgren extended Weibull's method, and much of current median rank techniques are based on the work of Leonard Johnson.

WEIBULL STATISTICAL METHOD

In 1939, Weibull developed a method and equation for statistically evaluating the fracture strength of materials based upon small population sizes. This method can and is applied to analyze, determine and predict the cumulative statistical distribution of fatigue failure or any other phenomenon or physical characteristic that manifests a statistical distribution. The dispersion in life for a group of homogeneous test specimens can be expressed by:

$$\ln \ln \frac{1}{S} = \boldsymbol{m} \ln \left(\frac{L - L_{\mu}}{L_{\beta} - L_{\mu}} \right); \quad L_{\mu} < L < OO \qquad (1)$$

where $\boldsymbol{L}$ equals the life (stress cycles), $\boldsymbol{L}_{\square}$ equals the characteristic life (stress cycles), $\boldsymbol{L}_{\mu}$ equals the location parameter or the time (cycles) below which no failure occurs, and $\boldsymbol{S}$ is the probability of survival as a fraction ($0 \leq \boldsymbol{S} \leq 1$).

The format of equation (1) is referred to as 3-parameter Weibull analysis. For most, if not all, failure phenomenon, there is a finite time period under operating conditions where no failure will occur. In other words, for a period of time, there is a zero probability of failure or a 100-percent probability of survival. For this period of time, the probability density function is nonnegative. This value is represented by the location parameter, $\boldsymbol{L}_{\mu}$. Without a significantly large data base this value is difficult to determine with reasonable engineering or statistical certainty. As a result, $\boldsymbol{L}_{\mu}$ in equation (1) is usually assumed to be zero. Accordingly, equation (1) is written as follows:

$$\ln \ln \frac{1}{S} = \boldsymbol{m} \ln \left(\frac{L}{L_{\beta}} \right); \quad 0 < L < OO \qquad (2)$$

This format is referred to as the 2-parameter Weibull distribution function. The estimated values of $\boldsymbol{m}$ and $\boldsymbol{L}_{\square}$ for the 2-parameter Weibull analysis are not equal to those of the 3-parameter analysis. As a result, for a given survivability value $\boldsymbol{S}$ the corresponding value of life $\boldsymbol{L}$ will be similar but not necessarily the same in each analysis.

By plotting the ordinate scale as $\ln\ln(1/\boldsymbol{S})$ and the abscissa scale as the $\ln \boldsymbol{L}$, a Weibull cumulative distribution will plot as a straight line. This plot is called a "Weibull plot." Usually, the ordinate is graduated in statistical percent of specimens failed $\boldsymbol{F}$ where $\boldsymbol{F} = [(1-\boldsymbol{S}) \times 100]$. Thus with a limited amount of failure data (number of cycles), a median rank can be determined according to Johnson and a Weibull plot generated, from which the life at various levels of failure probability determined.

Probabalistic techniques are desirable when only limited data are available. Virtual testing can be performed and validated with real world results.

Research Activities:

I. 2- and 3-Parameter Weibull Analysis

During my first summer faculty research fellowship in 2001, 2-parameter Weibull analysis was applied to failure data of wiper coatings used in the printing industry. The life of two different coatings was determined, and the viability of a replacement coating demonstrated. Subsequently, a technical presentation was made at the 2002 ISROMAC (Int'l Symposium on Rotating Machines). The full text of the paper appeared in the proceedings of the conference. During the 2002 Summer Fellowship, NASA-TM 2002-211381 Predictive Failure of Cylindrical Coatings Using Weibull Analysis was reviewed and appeared in final print. 3-Parameter techniques according to the method of Shimuzu were applied to wiper coating data during the academic year between the 2001 and 2002 Research Fellowships. The findings were presented at the 2002 STLE Annual Meeting in Houston, TX. The paper was reviewed, and a major revision of the text was completed while on site during the 2002 Summer Fellowship. The paper should appear in the October 2002 edition of the STLE Journal. NASA TM 2002-211819, entitled Comparative Fatigue Lives of Rubber and PVC Wiper Cylindrical Coatings, was edited during the 2002 summer.

II. Solid Model Generation for FEA studies

Results from finite element analysis studies are often used to validate or refine probabilistic studies. The NASA team that I was associated with has an on-going program to determine the life of jet turbine engine components, so that better preventative maintenance regimes can be established. Since last year, they have been trying to reverse engineer the primary components of the engine, create solid models, and then perform FEA to generate data to be used in probabilistic models. Last summer and the past academic year, I helped create a solid model of the turbine hub based upon physical measurements and photographs of the hub. The next step is to model the blades mounted on the hub. In April, an independent firm created stereolithographic images of the blade. Dense point cloud files were generated of the blade. It was hoped that solid surfaces could be applied over these point clouds. Unfortunately, this has proven to be an extremely challenging task—particularly since no funds are available to obtain the software to perform this task. I will continue to work on this problem during the coming academic year, while the team tries to secure funds to have the model commercially completed. This remains an important reverse engineering technique that should be available on the center, but currently is not.

III. Assembly/Component Studies

While various probabilistic techniques exist for determining the life of a component, an exhaustive literature search revealed that little work has been done to predict the life of a system if life information about the various components of the system are known; this is particularly true if the components of the system have significantly different distributions in component life. Several techniques for estimating system life were examined. These included:

1. Assuming that the distribution of the lives for each of the component were the same and determining the life from where L is the life of the system or respective

$$\frac{1}{L_S^{m_s}} = \frac{1}{L_1^{m1}} + \frac{1}{L_2^{m2}} + \frac{1}{L_3^{m3}} + \dots$$

   component, and m is the slope from the Weibull plot of the system and respective components.

2. Randomly creating assembled systems from components of randomly determined lives and then assuming the minimum life component in each system is the limiting life of the system.

3. The life of the system is equal to the product of the probabilities of failure of the components of the system

4. Assuming that the slope of the shortest lived component is slope of the system

Although the techniques work best for assemblies of similar slope (111, 222, 333, etc) lives for combinations of slopes were determined (123, 221, 311, etc) and are summarized in Table I. Additionally, the impact of the number of sample trials was also investigated (200, 30, 20, and 10). Typical results are summarized in Table I. While 30 samples gives reasonable agreement with assumed life values, some care must be given when using only ten samples. Further work is on-going in both of these areas.

Future Efforts:

1. <u>Solid Model Generation</u>: I plan to help complete the solid model of the turbine blade. I have a surfacing module available on my office machine at Georgia Southern that should be able to generate a solid model from the available point cloud data. Additionally, my office machine has greater resources that will minimize and hopefully eliminate system crashes.
2. <u>Technology Transfer to the Classroom</u>: I have already transferred reverse engineering skills and life prediction techniques to relevant courses at Georgia Southern University. Continued incorporation of lifing techniques is anticipated.
3. <u>Possible Future Funding:</u> I have begun to explore sources of future funding for projects that are of mutual interest to me and my NASA mentors. These projects will facilitate technology transfer to the classroom and be applied to the needs of my NASA colleagues—such as trying to obtain surfacing software to use in the classroom and apply to a NASA problem.. Additionally, Petroleum Research Grants should now be attainable based upon the expertise that I developed during two summer fellowships and continued association with my mentors. I also hope to apply for an internal Georgia Southern research grant that will allow me to continue to work on NASA related projects during the coming academic year and 2003 summer.

4. <u>Technical Papers and Presentations:</u> Three papers are currently being written based upon research activities of this summer. The first of these papers will be presented at the 2003 STLE Annual Meeting in New York City.

Name: **Sheng-Tao Yu**
Education: Ph.D., Mechanical Engineering
Pennsylvania State University

Permanent Position: Associate Professor, Mechanical Engineering
Wayne State University

Host Organization: Turbomachinery and Propulsion Systems Division
Colleague: 5880/Philip C. E. Jorgenson

Assignment:

Applying the Space-time CESE Method to the Combustion Phenomena and Aeroacoustics of a Pulse Detonation Engine

Professor Sheng-Tao Yu of Wayne State University will work closely with researchers at NASA Glenn Research Center to modify the original space-time CE/SE flow code to include the multiple species capability for computing unsteady chemically reacting flows. This will extend the capability of CE/SE code. It is anticipated that Professor Yu will set up several benchmark test cases with which we can validate the modified code. This work fits well with the goal of the Engine Systems Technology Branch for code development of new algorithms.

Research Summary Submitted by Fellow:

In the nine working weeks, collaborating with my NASA colleagues Drs. Philip Jorgenson and Sin-Chung Chang, I have accomplished the following items pertinent to the ongoing research activities of applying the space-time CESE method to the combustion phenomena and aeroacoustics of a pulse detonation engine:

1) We have identified that domain of interest for aero acoustics calculation should be from the PDE tube exit up to 50 feet from the engine. A new computer code based on distributed memory and parallel computation has been developed and applied to the calculation. We have shown that the acoustic sound is about 130 dB at 50' from the PDE exit, and the acoustic wave became linear at about 15 to 20 feet from the engine exit. Further comparison with the experimental data will be conducted in the near future.

2) A technical paper, entitled "Direct calculation of detonations by the CESE method with realistic finite rate chemistry," has been written. The paper is written based on previously presented AIAA conference papers and will be submitted for journal publication. In the paper, details of model equations and the extension of the CESE method for chemically reacting flows have been provided. In addition, I also spent significant amount of time in drafting another paper about treating stiff source terms in conservation laws in the context of the CESE method.

3) The newly developed computer codes for one and two-dimensional detonations using the CESE solvers have been tested and demonstrated at NASA GRC. The source codes have been delivered to the NASA colleagues.

Overall, it has been a very fruitful summer for me. I am bringing with me several new ideas back to my home institute, Wayne State, for the further development of the research works about applying the CESE method to chemically reacting flows.

Name:	**Michael L. Zellers**
Education:	Bachelors Degree in Computer and Information Science Cleveland State University
Permanent Position:	Instructor, Business Division – Computer Information Systems Lorain County Community College
Host Organization:	Engineering Design and Analysis Division
Colleague:	7735/Gail P. Perusek

Assignment:

Structural Dynamics Laboratory Database Development for Tracking Projects

The faculty fellow will work with the NASA Colleague to develop a working database for estimating, tracking, assigning, and scheduling projects that come through the NASA Structural Dynamics Laboratory (SDL). The database will accept manual inputs such as SDL Task Order (T.O.) #, Program Name, PR #, PR amount, Fixture #, Test Engineer, # Hrs. assigned to job, hours used, hours remaining, dates job will occur, Estimate #, SDL Test Report (TR) #, MP5 Task Order (T.O.)#, shaker/equipment used for test and/or special comments, and date of initial test request. It is expected that the database will be accessible by anyone with a password, searchable with various search criteria, and contain historical data that has been previously captured in EXCEL databases. The database should also be linked with a graphic representation of the schedule, which will contain selected information about each test, and be posted on the SDL website for use by the SDL staff and its customers.

Research Summary Submitted by Fellow:

My project this summer was to develop, test and implement a Web-based application for the Structural Dynamics Laboratory. The application's purpose was to assist in the scheduling, tracking and management of tests and other activities performed at the SDL. The application provides a calendar, which allows SDL Personnel and their customers to view the SDL's schedule and see details about the scheduled tests.

Previous to this application being developed, this information was maintained by Gail Perusek, the SDL Lab Manager and my NASA colleague, in a set of Excel spreadsheets. In addition, Gail used PowerPoint to create a calendar, which she posted to an internal website for customers to view. The problem with the previous system was that it was a labor-intensive process and there was much redundancy. There was considerable duplication of data between the spreadsheets as each were created to show particular pieces of information. Additionally, the calendar was created manually, which required Gail to manually recreate the calendar and post to the website whenever the dates of a test changed. Her previous site had an online customer test request form, which emailed Gail when a customer made a test. She would then have to manually take that data and populate all her spreadsheets.

I met with Gail in March to get a sense of the project's requirements and we exchanged emails prior to my actual start date of June 3rd. This was very important in the success of this project as it allowed me to do some preliminary design work and prototyping before actually coming to GRC on June 3rd. On June 3rd, then, I was able to hit the ground running.

Through our initial design discussions, we were able to identify the following main tasks for the project:

- Develop an Access Database to record SDL scheduling information
- Develop a Web Page that will take scheduling information from the database and display it in a calendar format.
- Develop Content Management Tools that will allow an administrator to maintain the database
- Automatically integrate customer requests into the scheduling database.
- Any additional reporting requirements

Largely because we got off to such a good start, I was able to address all of these main tasks. In addition, I had sufficient time to address additional functionality that was not in our original specification, but was determined to be important – most notably Time Entry, and a flexible report generator that interfaces with Microsoft Excel. Throughout the process, we showed the application to various NASA personnel to solicit their feedback. In many cases, I incorporated their suggestions into the application. Another notable accomplishment not included in the original specifications was the importing of some archival data, going as far back as 1995 into the application. This application is linked to and from the new SDL Facilities Portal Page.

The technical specifications of the project are as follows:

- Microsoft IIS 4.0 Web Server
- Access Database
- ASP Pages
- Client-side Javascript
- Cascading Style Sheets
- SMTP Mail Server

The application was thoroughly tested – both by myself using various testing platforms (PC, Mac, browser type and version, screen resolution) and by actual users performing beta testing. It has been documented both from a technical perspective and from a site administrator perspective. Some testing was done at the ITrack facility using the automated testing tools to ensure Section 508 compliance.

On a personal note, this has been a very satisfying experience. I see many benefits from this experience, personally and professionally, which I aim to use to benefit Lorain County Community College and our students. These benefits include:

- An increased familiarity with web site accessibility requirements. I worked as a software developer for years in the private sector where, unfortunately, accessibility is not always a top priority. Learning more about accessibility and it's importance first hand will allow me to address that issue better with my students and also to stress accessibility in any distance learning web courseware that we develop.

- "Real World" experience in a different environment. It is critical for teachers in my field and environment to have "real world" experience. It allows the instructor to make the course materials much more relevant to the student. Although I have an extensive background as a software developer, this project offered some new challenges and was in a different environment – and as such will provide a broader range of experience on which I can draw.

- An increased awareness of NASA Glenn Research Center and the opportunities it might provide for me and my students

- This is a very stimulating and exciting work environment and I found this project rejuvenating.

Lastly, on a personal note, I would like to thank everyone here who has made this such a great experience starting with my colleague, Gail Perusek, and extending to everyone I had contact with here.

Name: **Fredy R. Zypman**
Education: Ph.D., Physics
Case Western Reserve University

Permanent Position: Professor, Physics
Yeshiva University

Host Organization: Structures and Acoustics Division
Colleague: 5960/Phillip B. Abel

Assignment:

Professor Zypman will tackle some of the theoretical issues associated with our efforts to understand material mechanical properties at the atomic level. These issues involve improving the highly successful atomistic modeling methods, Equivalent Crystal Theory (ECT) and the Bozzolo-Ferrante-Smith method (BFS) which were developed at NASA Glenn, by extending their ability to deal with many-body effects. Given Professor Zypman's experience in tip-specimen interaction modeling, a further exploration of the fundamentals of materials interaction/modeling should be beneficial in our use of an existing quantitative mechanical indenter coupled to a scanning tip-specimen interaction apparatus. In particular, his efforts will be directed toward understanding tribology and materials properties at small, e.g. MEMS/NEMS scales. Professor Zypman is expected to direct his efforts to aid our capability and capacity to model defects using ECT, BFS and techniques, which he has developed in his research. Professor Zypman will work either independently or in collaboration with local researchers as appropriate.

Research Summary Submitted by Fellow:

Generalization of Equivalent Crystal Theory to Include Angular Dependence

In the original Equivalent Crystal Theory, each atomic site in the real crystal is assigned an equivalent lattice constant, in general different from the ground state one. This parameter corresponds to a local compression or expansion of the lattice. The basic method considers these volumetric transformations and, in addition, introduces the possibility that the reference lattice is anisotropically distorted. These distortions however, were introduced had-hoc. In this work, we generalize the original Equivalent Crystal Theory by *systematically* introducing site-dependent directional distortions of the lattice, whose corresponding distortions account for the dependence of the energy on anisotropic local density variations. This is done in the spirit of the original framework, but including a gradient term in the density. This approach is introduced to correct a deficiency in the original Equivalent Crystal Theory and other semiempirical methods in quantitatively obtaining the correct ratios of the surface energies of low index planes of cubic metals – (100), (110), (111). We develop here the basic framework, and apply it to the calculation of Fe (110) and Fe (111) surface energy formation. The results, compared with first principles calculations, show an improvement over previous semiempirical approaches.

CRITICAL PHENOMENA IN STICK-SLIP IN FRICTION

This paper presents experimental results of stick-slip in dry friction. The data, obtained with a tribometer, consists of a time series of a metal sensor position as it scans different regions of a metal sample. The time series presents jumps a various sizes corresponding to sticking and slipping between the two surfaces. An analysis of the data shows that the probability distribution of jump sizes follows a power law. In addition, the frequency power spectrum follows a $1/f^{\square}$ pattern with $\square$ in the range 1.1 to 1.3.

APPENDIX A

2002 LECTURE SERIES

2002 LECTURE SERIES

June 7
Dynamics of Bubble-Generated Convection and its Effects on Microgravity Crystal Growth
Mohammad Kassemi
Research Associate Professor
National Center for Microgravity Research
NASA Glenn Research Center

June 14
Flame Synthesis of Carbon Nanotubes Using Aerosol and Supported Catalysts
Randy L. Vander Wal
Research Scientist
National Center for Microgravity Research
NASA Glenn Research Center

June 21
Uncoupling Mass Transport Issues from Forces on Cells in Microgravity: Predicting the Mass and Fluid Transport in a Perfused and Stirred Culture System
John P. Kizito
Research Scientist
National Center for Microgravity Research
NASA Glenn Research Center

June 28
Mechanisms of Transport of Heavy Chemicals in Riverbed Sediments, Significance to Remediation of the Hudson River
Wilbert Lick
Professor of Mechanical and Environmental Engineering
University of California, Santa Barbara

July 12, 2002
The Physics of Liquid Spreading on Solid Surfaces
Enrique Rame
Research Scientist
National Center for Microgravity Research
NASA Glenn Research Center

July 19

Pattern Formation in Diffusion Flames Embedded in on Karmen Boundary Layers

Vedha Nayagam
Research Associate Professor
National Center for Microgravity Research
NASA Glenn Research Center

July 26

Characterization & Control of Two-phase Flow in Microchannels (PEM Fuel Cells)

Jeffrey S. Allen
Research Scientist
National Center for Microgravity Research
NASA Glenn Research Center

APPENDIX B

2001 EVALUATION QUESTIONNAIRE

NASA GLENN RESEARCH CENTER

2002 NASA FACULTY FELLOWSHIP PROGRAM

(You can complete and return this form electronically. Tab or <Shift>Tab among questions.)

Please return by e-mail attachment to Toni.Rusnak@grc.nasa.gov.

Name: ______________________________

Home Institution: ______________________________

Glenn Organization: ______________________________

Area of Research: ______________________________

Colleague: ______________________________

You may elaborate on any question in the Comments section at the end.

1. Was this your first period of residence at the Center? <Select>

2. If so, how did you learn about this program?

3. Was the contact with your NASA colleague prior to the start of your fellowship adequate? <Select>

4. Are you familiar with the research objectives of the organization you worked in this summer? <Select>

5. Do you feel the research you were engaged in was of importance to the Center and to NASA? <Select>

6. Was your assignment sufficiently challenging and consistent with your professional training? <Select>

7. Were the research facilities provided to you satisfactory? <Select>

8. Have you developed new areas of research interest as a result of the fellowship? <Select>

9. Are you interested in maintaining a continuing research relationship with the organization you worked in this summer? <Select>

10. Have you discussed with your NASA colleague the possible preparation of a proposal to support future research at your home institution or at the Center? <Select>

11. Are you satisfied with your understanding of the Center's research proposal process? <Select>

12. Do you expect that those at your home institution who affect decisions on promotion and tenure will give you credit for participation in this program? <Select>

13. How and to what degree has the fellowship affected your research capabilities?

14. How and to what degree will the fellowship affect your teaching?

15. How did the fellowship stipend compare with your salary at your home institution?

16. What would you regard as an adequate stipend?

17. What is your evaluation of the weekly lecture series?

18. How would you judge the overall balance of time allotted for research, lectures, and social events?

19. Were your office accommodations suitable? <Select>

20. How would you evaluate the program overall?

Comments: